Arnold Schwarzenegger
Governor

COMMERCE ENERGY BIOGAS/PV MINI-GRID RENEWABLE RESOURCES PROGRAM

PROJECT 3.2 BUILDING INTEGRATED PV TESTING AND EVALUATION PROJECT

PIER FINAL PROJECT REPORT

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California Energy Commission
Public Interest Energy Research Program

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Table of Contents

List of Tables

List of Figures

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with research, development, and demonstration (RD&D) organizations, including individual, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

What follows is a project final report for the PIER Commerce Biogas/PV Mini-Grid Renewable Resources RD&D Program, Contract Number 500-00-036 conducted by the Commerce Energy Team, comprising Commerce Energy; Itron, Inc.; CH_2MHill; Behnke, Erdman, and Whitaker Engineering, Inc. (BEW Engineering); Renewable Energy Development Institute (REDI); and Zaininger Engineering, Inc (ZECO).

For more information on the PIER Program, please visit the Commission's website at: www.energy.ca.gov/research/index.html or contract the Energy Commission's Publications Unit at 916-654-5200. Or you may review the PIER Commerce website at: www.pierminigrid.org, which was created for this contract and summarizes each project of the contract. A project-specific website at www.pierminigrid.showdata.org contains additional information along with historical and real time data of the photovoltaic systems under analysis.

Abstract

Commerce Energy Biogas/PV Mini-Grid Renewable Resources RD&D Program - Project 3.2 Building Integrated photovoltaic (PV) Testing and Evaluation

Project Purpose
The purpose of this project was to perform side-by-side evaluations of commercially available PV systems and component technologies, to compile objective, consumer-friendly information on the costs and performance parameters of those systems, to document the methods and results, and to broadly disseminate the results. This type of information is not currently available from any one source and is needed by the PV-buying public.

Project Objectives

- Select, procure, install, and evaluate three candidate PV Systems to inform Commerce Energy in implementing Project 3.3 BIPV on Public Buildings
- Determine flaws, weak points, poor design features, etc. and offer suggested fixes
- Evaluate selection, ease of installation, performance, other issues that may impact life-cycle costs
- Monitor and report on system performance for 12 months
- Develop recommendations for system purchases.
- Repeat the process for three small, residential scale systems

Project Outcomes

- Installed and evaluated 15 Commercial and Residential-scale PV Systems
- Prepared reports covering 6-month and 12-month performance, detailed comparison of different module and system ratings, magazine-style presentations of system evaluations, system evaluation methodologies
- Interactive web site for this project had 4500 visitors and the project team trained 170 PV installers and other interested parties

Project Conclusions
This effort directly supports the Commerce Energy Biogas/PV Mini-Grid Research, Development and Demonstration Program and the Energy Commission's PIER Renewables Program element by helping to better understand the affordability and diversity of renewable energy systems.

Executive Summary

The Building Integrated Photovoltaic (BIPV) Testing and Evaluation Project, under which this work was performed, is one of several projects that make up the Commerce Energy Biogas/PV Mini-Grid Renewable Resources RD&D Program (visit www.pierminigrid.org). Commerce Energy Corporation and the Energy Commission Public Interest Energy Research (PIER) program fund the work. The project will develop consistent informative reviews of commercially available PV systems, including the tests and procedures required to conduct those reviews. These reviews cover component selection, system design and documentation, installation, and performance. Additionally, a technology transfer component of the project provided information to the public through project reports, technical conference papers, presentations, comprehensive website (www.pierminigrid.showdata.org), and targeted workshops.

The project successfully obtained, installed, and evaluated 12 commercial-scale (i.e. "large" systems) and 3 residential-scale (i.e. "Small") PV systems representing

- 9 cell technologies
- 10 module manufacturers
- 4 system integrators
- 3 inverter manufacturers
- 7 mounting methods

The large systems operate on the roof of the Inland Empire Utility Agency (IEUA) headquarters building in Chino, California; the small systems were installed at the PVUSA facility in Davis, California.

Immediately following installation, reviews of each system were covered in initial characterization reports, which discussed the installation, documentation, and initial testing results. Separate large and small systems performance summaries were prepared following 6-months and 12-months of operation. Two interim reports examined technical issues related to evaluating PV performance, specifically performance indexing improvements and understanding maximum power point tracking of inverters. And, finally, two consumer confidence guidelines were prepared that summarized the results into magazine-style review articles intended for system designers and end users, complete with ratings and rankings of each system. The consumer confidence guidelines also contained annexes detailing the procedures used for analyzing the systems in a form suitable for submission to a consensus standards organization such as Institute of Electrical and Electronics Engineers (IEEE) or American Society for Testing and Materials (ASTM).

System Performance Results

Over the course of the project, researchers presented detailed analyses of the data and observations regarding the systems. A recurring theme was that estimating the ac energy output of a PV system before purchase involves estimating the collective effects of a series of small loss factors that individually tend to be overlooked or dismissed as too minor to consider. These factors tend to affect either the as-installed power rating or the operation of the system over time. Fortunately, it turns out that with good installation and maintenance practices, the installed rating can be used to predict energy production. While none of this is particularly new information, a challenge remains in obtaining an appropriate power rating among the available options.

The discrepancy between power ratings based on standard test conditions (STC), commonly measured in the factory and quoted by PV module manufacturers, and ratings based on PVUSA Test Conditions (PTC)[1] used for field measurements arises for a variety of well-understood reasons including:

- PV modules produce less power at the higher temperatures experienced outdoors.
- wire resistance usually dissipates a few percent of the potential power on a system level.
- PTC AC power is measured at the output of the inverter, which also dissipates some power, instead of directly at the module outputs as is the case with STC *dc* power reporting.
- Lot-average module nameplate power is biased downward due to the standard manufacturing practice of "binning" modules based on normal variations in power output (see **Figure 1**).
- Module-to-module variability, also termed mismatch, when connecting strings of modules, even when these modules fit within the manufacturer's published range.

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[1] A third rating condition, designated "California Energy Commission (the Energy Commission)" in this project is used for calculating both Emerging Renewables Program (ERP) and Self Generation Incentive Program (SGIP) rebates. It is a mathematical conversion of PV module nameplate STC rating to that expected under PTC conditions (a dc value) that is then converted to an ac value using a nominal inverter efficiency value. While the Energy Commission takes into account a large percentage of the normal system losses ignored by the STC rating, the difference between the Energy Commission and PTC reflects the remaining losses that a PV system encounters when operating in the field.

- Light-induced degradation.
- Shading and dust.

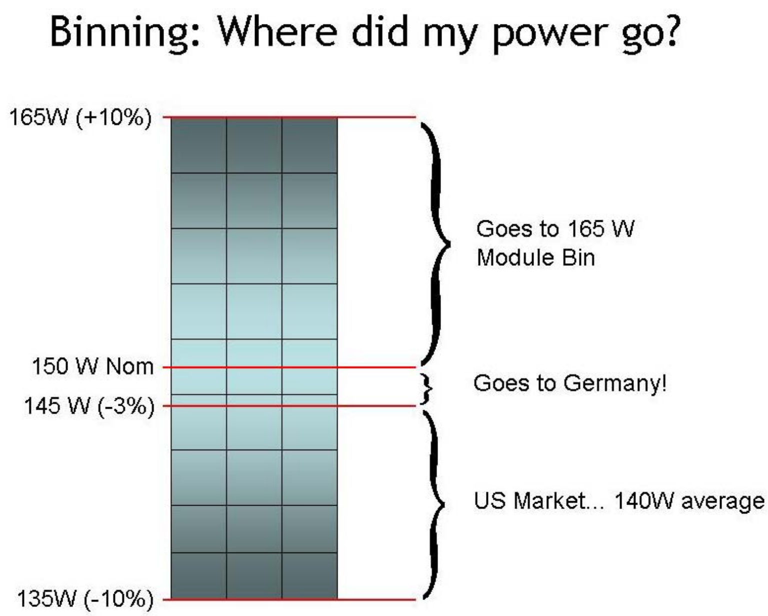

Figure 1. Illustrative example of a hypothetical 150 Watt rated (nominal) module with a claimed ±10% tolerance. Based on the US (UL 1703) 10% allowable tolerance, German 3% procurement tolerance, and other anecdotal information.

As seen in **Figure 2**, the predictable effects conspire together such that a PTC rating is usually about 80 percent of the STC rating, while the variable effects (which become "known" as soon as the PTC rating is measured, but do affect pre-purchase decisions) cause this ratio to vary by ±10 points (95 percent confidence). This graph also shows that the Energy Commission rating (a simplified prediction of the PTC value based on manufacturer reported data) is on average 9 percent higher than the PTC values, demonstrating that the Energy Commission data are too optimistic for use as actual installed system ratings. Part of this arises from the purposeful omission of known system-level loss mechanisms from the Energy Commission calculation for simplicity, and part is due to the "binning" effect.

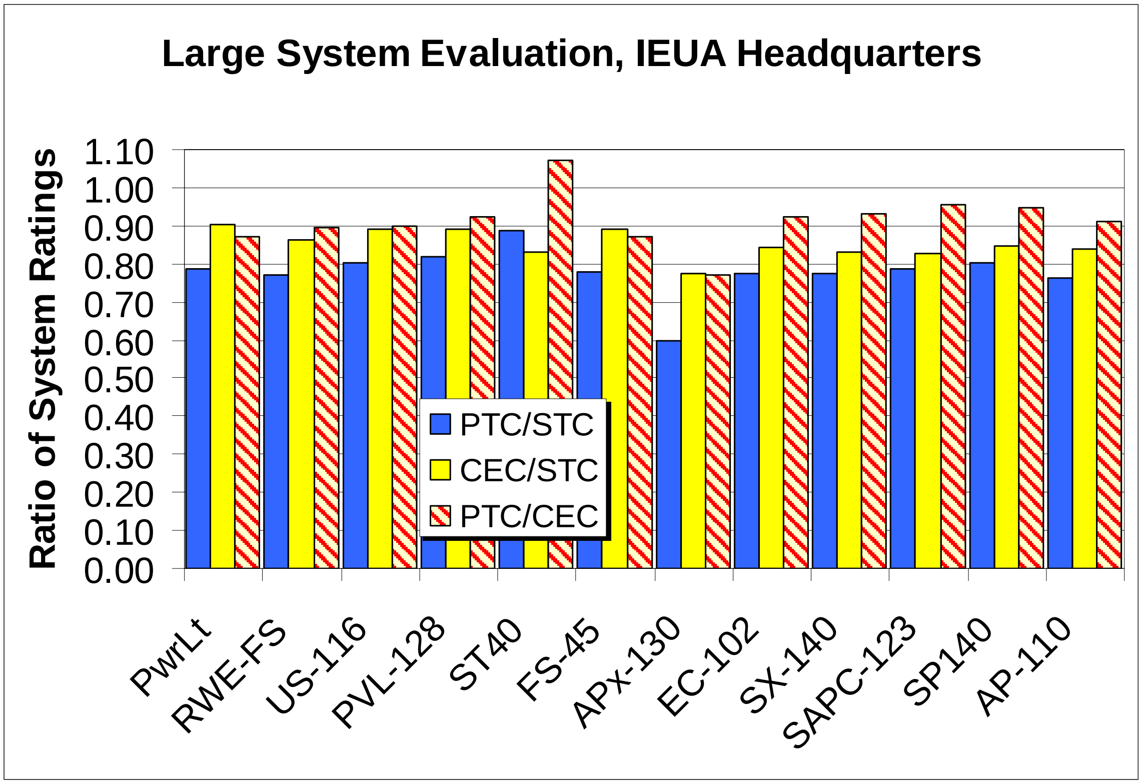

Figure 2. Ratios of different system ratings

Once a PV system is installed, it is affected by predictable factors such as solar position (sunrise to sunset), array orientation (arrays tilted to the west miss morning energy), and shading (even a small shadow can have a large influence), while uncertain factors such as atmospheric conditions (clouds) and soiling (for example, dust in rural areas and diesel particulates in urban areas) are usually accounted for by averaging over long periods. Fortunately, over the long-term the solar position and weather average out to a predictable energy availability at each installation site that is typically quoted in "peak sun hours" per day or year.[2] The system energy yield[3] can similarly be quoted in "peak operating hours" per day or year, and these numbers should be similar if the rating used represented the actual system operation. **Figure 3** shows the energy yield values obtained for the three residential-scale small systems, computed by dividing energy produced by different estimates of system rating.

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2 Daily or annual energy in kWh/m^2 divided by the reference irradiance, usually 1000W/m^2, the result of which has the units of hours. This value can be thought of as the number of hours the sun would have to shine at the reference irradiance to provide equivalent energy.

3 Yield is the daily or annual energy output of the PV system in kWh divided by system rating in kW, which also results in units of hours, and is the number of hours the system would have to operate at its rated output to generate an equivalent amount of energy.

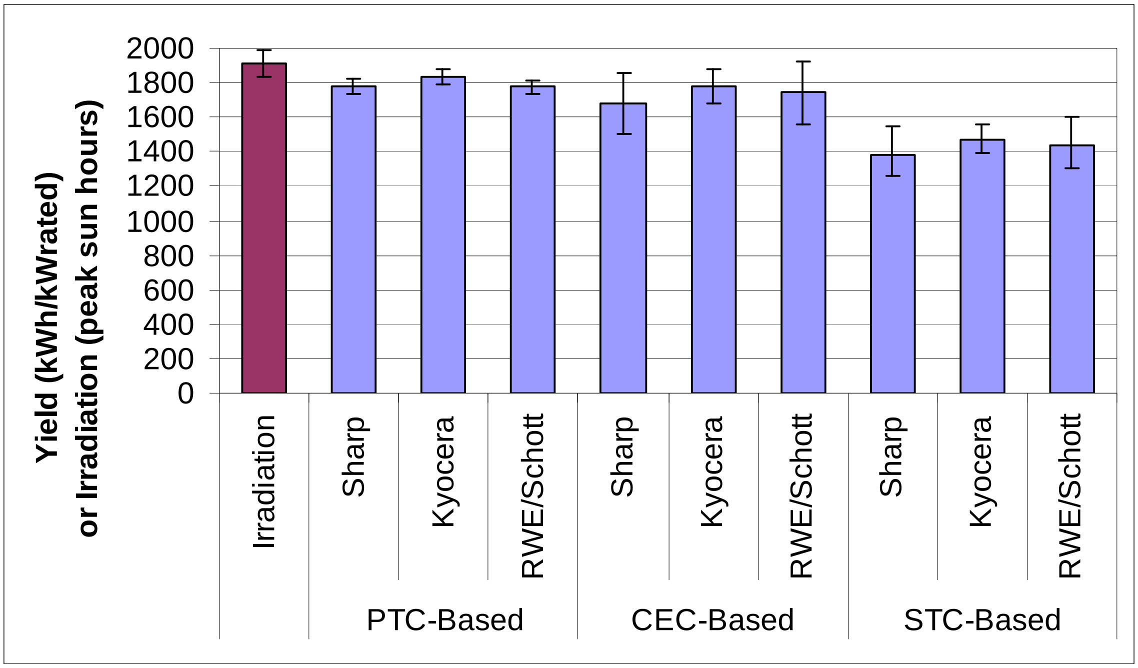

Figure 3. Summary of Yields Referenced to Different Ratings for the PIER Small Systems.

In the case where a PV system owner is fortunate enough to have a (PTC) power rating measured after the system is installed, this value can be combined with the expected yield both to predict long-term energy production (for example, using **Figure 3**) and to detect partial system failures by comparison with ongoing measures of system output. In the absence of such a rating, the owner must wait for about three years' of worth of energy production before the long term performance of the system will become evident among typical short term weather variations.

Another use of the yield information gathered for these 15 systems is to correlate the system performance at these two locations to other locations throughout California and beyond. With an understanding of the relative irradiation and temperature variations of a site relative to the Chino and Davis sites, a designer could fairly accurately predict how a similarly installed system would operate in another location.

Technology Transfer

Technology transfer from the project has been broad and successful. The project webpage, which attracted 4,500 visitors, included links to the reports and presentations, descriptions of the project, the test sites, and the 15 systems, and provided access to real-time and archived performance data. Three-day advanced PV workshops were provided in Northern and Southern California, reaching 170 installers and other interested parties.

Lessons Learned

Several unexpected lessons were learned as a result of fielding these 15 systems. Difficulties were experienced with siting of the 12 systems on the commercial flat rooftop: parapet walls, an HVAC shroud, and numerous skylights made it challenging to provide equal solar access to all systems.

Several inverter issues were identified and corrected during the course of the project: two related to software anomalies, one related to a very tight AC voltage operating window, and one related to insufficient air movement in the inverter room.

Due to the higher than expected operating temperature of one of the systems and the lower-than-expected rated voltage of the PV module in that system, performance for that system was well below expected. Additional modules can be added to this system to rectify the operating problem.

Another notable lesson occurred during construction of one of the residential systems at the PVUSA site in Davis when a rodent damaged several of the connectors on the cables in the array. These connectors are ubiquitous in the industry, and this damage points out another potential concern for PV system designers and installers.

Recommendations

As described above, the simplified system rating calculation employed by the Energy Commission Emerging Renewables Program is based on the nominal STC ratings provided by the manufacturers, and ignores both the variability in production ratings and the downward bias introduced by production “binning”. We recommend changing this calculation to be based on the manufacturer’s minimum warranted rating. This would change the typical effect of binning on final system output from yet another 7 percent shortfall to a 3 percent consumer windfall, which would coincidentally account for most of the remaining loss mechanisms in well-designed systems that the Energy Commission calculation ignores. The random effects described above would not be removed, but on average the Energy Commission rating would provide an improved initial estimate of system power rating. To reduce uncertainty in the estimate so that feedback on installer performance can be evaluated, we recommend that a statistical sample of installed systems have an independent initial system evaluation performed.

In summary, we find that the state of the PV industry is healthy, there is a wide variety of high quality products from a number of vendors, and installers are figuring out what customers want and what works best. There remains, of course, work to be done, and the Recommendations section discusses several industry gaps that, in support of the California Solar Initiative's 3,000 MW goal by 2017, the Energy Commission can play a vital role in filling:

- A PV module rating requirement to go along with the already enacted inverter performance test requirements.
- Continuation of the monitoring of the existing system to obtain long term performance and reliability information.
- Expansion of the monitoring, evaluation, and tech transfer to carry on the consumer confidence evaluations to other products.
- Use these test systems to validate PV system performance models being developed at the Energy Commission for use in Title 24 compliance calculations.

1. Introduction

In a few short years, the photovoltaics industry has exploded, going from an industry that easily survived off the table scraps of the integrated circuit industry to one that dominates the world usage of silicon. Such growth is not without its risks. While PV module manufacturers add new capacity to their production lines, PV installers have had to add to their ranks with little formal training available to help them become educated. New modules and inverters coming from old and new manufacturers promise improvements in cost, performance, and reliability, but have few venues in which to prove themselves in front of a large audience.

The PIER Building Integrated Photovoltaic (BIPV) Testing and Evaluation Project, a component of the Commerce Energy Biogas/PV Mini-Grid Renewable Resources Program, was set up to provide a public venue where components and systems can be compared, providing the consumer – including end users and designer/installers— confidence in their performance.

Small and large PV systems installed at PVUSA in Davis and Inland Empire Utility Agency (IEUA) in Chino, California.

Are the California PV consumers getting what they pay for?

A key aspect of energy system affordability is a realistic assessment of component and system performance and longevity. For years, the PV industry has relied on manufacturer literature to judge the performance and suitability of products for various applications. Especially in this expanding market, installing contractors are confronted with products that have no third-party evaluation, so they must use their clients as field-test guinea pigs. The much larger markets in Europe and Japan have imposed stringent rating requirements while the United States lacks any such requirements.

There is anecdotal evidence that, as a result of this disparity, the United States consumers are getting PV modules that are within the manufacturers' rating tolerance range but significantly at the bottom of that range. Equipment has optimistic performance claims, and the customers are disappointed with the actual performance of their systems. This situation places installation contractors in a difficult position of questioning whether the products they use will perform as advertised. Manufacturers that attempt to buck the trend and provide more realistic product information are likely to lose market share when consumers base their buying decisions on lowest cost and dollars per advertised watt.

Because the performance of PV components, especially PV modules, is strongly dependent on operating conditions, rating and evaluating these components are complex. Not only does characterization require accurate measurement of appropriate parameters, but it also requires a thorough understanding of the long-term operating issues and the ability to translate and interpret results.

While component performance is certainly important, installed system performance is even more important and factors in the interaction of all the components. The goals of a properly designed and installed system should be safety, superior performance, high reliability, quality of components, ease of installation, code compliance, and low cost/high value. The compromises the system designer and installer make to meet an initial cost goal may have serious implications on the other listed goals, adversely affecting life cycle cost and, therefore, affordability.

Where can the consumer find objective PV product performance evaluations?
Credible third-party performance information on PV modules, inverters, and other components relevant to the California market is not readily available to the public.

The Florida Solar Energy Center (www.fsec.ucf.edu) has a program for evaluating and certifying residential PV systems to be sold under that state's rebate program. Although similar to the Energy Commission Emerging Renewable Program's (ERP) approved component list, the Florida program takes the process a step further by reviewing and approving system designs. While the California program requires that PV modules and inverters be listed to Underwrites Laboratory (UL) safety specifications, and inverters tested to a specific set of performance requirements, the limited module performance information is based on manufacturer-provided data, which is sometimes suspect and typically without third-party verification. There is also no information on or requirements for the systems in which these components will be used.

Although the Florida review program is largely an engineering evaluation of documentation, it also requires that modules be tested by a third-party lab and are within 10% of rated values, and that the relevant components have passed their respective IEEE and UL tests. One limitation of the Florida program is that it considers only systems sold into its market and only involves an engineering evaluation of the available documentation for small grid-connected systems. PowerMark Corporation, Arizona State University PV Test Laboratory, and others are developing PV module and system certification programs (www.powermark.org). The Energy Commission has yet to adopt/impose such a certification program, a step that the project team wholeheartedly supports and that would provide a key a piece of the puzzle.

Enter the PIER BIPV Testing and Evaluation Project

System affordability must be based on realistic performance estimates. The expanding California renewables market needs a trustworthy source of quantitative and qualitative information for both components and systems. This need existed when this project was conceived in 2001, and it is even more critical now with the California Solar Initiative. Ideally, what would be most useful is a consumer reports approach to PV evaluation. As part of the Commerce Energy (formerly Commonwealth Energy) Biogas/PV Micro-Grid Renewable Research Program, BEW Engineering established a PV Evaluation Project. This project encompassed two primary evaluation tasks and a list of technology transfer activities:

- Comprehensive PV System Evaluation
  - Commercial Scale Systems (referred to as “Large Systems”)
  - Residential Scale Systems (referred to as “Small Systems”)
- Tech Transfer
  - Technical Reports
  - Web Presence
  - Workshops
  - Technical Papers and Conference Presentations

Through these tasks, the project developed, documented, and communicated definitive performance information. The information is available for the Commerce team and others participating in the ERP Rebate program or the California Public Utility Commission (CPUC) Self-Generation Incentive Program (SGIP), and it can be used to supplement and field-verify any performance ratings established by others.

2. Project Approach

The BEW Engineering PV System Evaluation Project was designed to provide side-by-side evaluation of available PV system and component technologies, information that is needed by the PV-buying public but not currently available from any source. The project promised to provide the following products:

- Real-world performance data.
- On-line performance comparisons.
- Systems optimized for the California market; results useful for all markets.
- Consumer confidence guidelines (Consumer's Report for PV).
- Purchase guidance to Commerce Energy BIPV program.
- Workshops and conference presentations.

This project performed side-by-side evaluations of commercially available PV systems and component technologies and compiled objective, consumer-friendly information on the costs and performance parameters of those systems. This type of information is not available from any source.

This effort directly supports the Commerce Biogas/PV Micro-Grid Renewable Research Program and PIER by helping to understand better the affordability and diversity of renewable energy systems.

PV systems were installed and monitored for 12 months to provide "real-world" performance data relevant to building-integrated PV applications. Information on design features, flaws, weak points, and others were evaluated to develop suggested fixes. Factors affecting overall system value, including ease of installation, component selection, component failures, and performance factors, were assessed and reported.

This information was used to develop a rating system for use by consumers, and compiled into a Consumer Confidence Guidelines document. Manufacturers and system integrators will also find this information valuable in selecting, designing, and installing PV systems. In addition, the project results were intended to be used to provide purchase guidance to the Commerce Building Integrated PV Program (Project 3.3).

Real-time performance data as well as reports on performance comparisons between installed systems are available online at www.pierminigrid.showdata.org.

While the PV systems under evaluation were selected for their application to the California market, results are clearly relevant and useful for all national markets. The procedures developed in this program will provide the basis for the development of standardized tests to be adopted nationwide. This project is linked with efforts to produce a national PV system testing procedure underway for the U.S. Department of Energy at Sandia National Laboratories. The results of this project will be used to help establish standards to be published by organizations like the Institute of Electrical and Electronic Engineers (IEEE) or the American Society for Testing and Materials (ASTM).

2.1 Project Goals and Objectives

The project goals and objectives as listed in the contract work statement are presented below.

The goals of Building Integrated PV Testing and Evaluation project include the following:

- Address the gap between future third-party certified PV component and system performance results and currently available information from manufacturers.
- Provide an independent comparative evaluation of PV systems critical to Project 3.3 and to the ERP Rebate Program.
- Provide decision-making information on those PV systems.
- Improve the quality of systems installed in Project 3.3 through directed training.

The objectives of this project include the following:

- Select, procure, install, and evaluate three candidate PV Systems for implementing Project 3.3 BIPV on public buildings.
- Determine flaws and offer suggested fixes.
- Evaluate selection, ease of installation, performance, other issues that may affect life-cycle costs.
- Monitor and report on system performance for 12 months.
- Develop recommendations for system purchases.
- Repeat the process for three small, residential scale systems.

2.2 Scope

The project is composed of the following major task areas:

Building Integrated PV Testing and Evaluation Test Plan

This task entailed the development of a test plan that includes formation of a Technical Advisory Committee to oversee the project, development of criteria for site selection and PV systems selection, system testing and monitoring plans, data acquisition protocols, and reporting procedures.

Building Integrated PV Testing and Evaluation Project

This work was divided into two categories of systems intended for building integration:

- Large Systems – three nominal 20 kW systems representing large commercial rooftop systems each configured as a single or multiple building blocks.
- Small Systems – three nominal 2 kW residential/small commercial rooftop systems.

The project intended to the extent reasonable and practical, to select and purchase systems so that they represented off-the-shelf, commercially available products, and not products specially selected by the vendor. They were to be installed in accordance with the test plan, and monitored for 12 months. Expected deliverables included documentation of the selection, acquisition, and installation process; initial characterization reports; 6-month and 12-month exposure and operations reports, and consumer confidence guidelines.

Technology Transfer and Reporting

The proposed tech transfer activities featured a webpage with real-time operational and comparative performance information, project technical reports, technical papers and presentations and workshops, a final report, and coordination with the Renewables Program Advisory Committee (RPAC).

2.3 Tasks

A list of the contract tasks and deliverables is shown in **Table 1**.

Table 1 Project 3.2 Task Description

#	Title	Deliverables
3.2.1	BI PV Testing and Evaluation Test Plan	Draft and Final BIPV Testing and Evaluation Test Plan
3.2.2	Comprehensive PV System Comparison	
3.2.2.a	Large Systems Testing	1) System site selection, permitting
		2) DAS letter of Notification
		3) Initial Characterization Report, 1st System
		4) Initial Characterization Report 2nd System
		5) Initial Characterization Report 3rd System
		Critical Project Review Meeting
		6) 6-Month Exposure and Operation Report
		7) Interim Report
		8) 12-Month Exposure and Operation Report
		9) Consumer Confidence Guidelines
3.2.2.b	Small Systems Testing	1) System site selection, permitting
		2) DAS letter of Notification
		3) Initial Characterization Report, 1st System
		4) Initial Characterization Report, 2nd System
		5) Initial Characterization Report, 3rd System
		Critical Project Review Meeting
		6) 6-Month Exposure and Operation Report
		7) Interim Report
		8) 12-Month Exposure and Operation Report
		9) Consumer Confidence Guidelines
3.2.3	Technology Transfer	1) Initial Web Page Design
		2) Web Page updates
		3) Technical Papers and Presentations
		4) Three 3-day Workshops
3.2.4	Final Report for Project 3.2	1) Draft BI PV Testing and Evaluation Report
		2) Final BIPV Testing and Evaluation Report.

2.3.1 BI PV Testing and Evaluation Test Plan

This task required the project personnel to lay out the detailed test plan for the rest of the BIPV Evaluation project for review and approval by the Technical Advisory Committee (TAC). The goals outlined in the following two sections were produced in this plan. At the time this document was being developed, the TAC was established.

Invitations were extended to a handful of experts throughout the country who could provide independent expert review of the plan and the products of the project as those were developed. The members of the TAC are:

- Ward Bower, Sandia National Laboratories.
- Jim Dunlop, Florida Solar Energy Center (retired).
- Jennifer Harvey, New York State Energy Research and Demonstration Authority.
- Matt Lafferty, Sacramento Municipal Utility District (retired).
- Kevin Lynn, Florida Solar Energy Center (replaced Dunlop).
- Peter McNutt, National Renewable Energy Laboratory.
- Andy Rosenthal, Southwest Technical Development Institute.
- Fred H Schwartz, San Francisco Public Utilities Commission (retired).
- Bruce Vincent, Sacramento Municipal Utility District (replaced Lafferty).

2.3.2 Comprehensive PV System Comparison

The comprehensive system comparisons for large and small PV Systems are similar, but due to typically different system capacities, installation requirements and test locations, they are considered separately here.

2.3.2.1 Comprehensive Large PV System Comparison

The large system evaluation covered the selection, installation, operation, monitoring, and evaluation of three independent 20 kW PV systems. These systems were intended to be indicative of the kinds of Building Integrated PV hardware that was expected to be installed under Project 3.3 of the Commerce PIER program. While these sample systems did not all represent actual building integrated products (or those designed to replace traditional building roofing, glazing, or cladding materials), they were representative of then-available electrical technologies (PV cells/modules, structures, inverters, wiring, and so forth) that were used or could have been used to make BIPV products.

2.3.2.1.1 Large System Site Selection

The large PV systems were co-located (at a single site) for fair and impartial comparison of the selected technologies. The site had an adequate installation area (20,000 ft^2) for 60 kW of PV (which could require as much as 10,000 ft^2) along with associated power conditioning and monitoring equipment. The roof of the selected site was a flat-roof commercial building with a fairly significant number of protrusions (HVAC equipment, skylights, vents, and so forth), but the spacing between these protrusions was large enough to allow array placement with minimal interference. As installed, the arrays had an unobstructed view to the east, south, and west with almost no shading.

As the cost of these systems was borne by the project participant, it was ideal that this location allowed the participant to take advantage of both the energy generated and the public relations value of using a renewable energy source. The co-location of the compared systems allowed the project participant to access CPUC Self-Generation Incentive program rebate funds that were available for systems over 30kW.

2.3.2.1.2 Large System Selection

Systems were bought from dealers, distributors, or otherwise to ensure that the components were not specially selected by the supplier. While we had initially planned to competitively bid the three systems, our decision to do the multi-string system meant we would be buying products from nearly every supplier. The TAC reviewed and prioritized a list of potential products. We then worked with Commerce to obtain the best available prices and issued purchase orders to the equipment dealers with the lowest costs. Equipment selection criteria included the following:

- ☒ Price
- ☒ Supplier experience
- ☒ Degree to which proposed system met program objectives
- ☒ Degree to which proposed system added variety to project
    - ☑ At least one single-inverter system
    - ☑ At least one string-inverter based system
    - ☑ Variety of modules
    - ☑ Variety of inverters
    - ☑ Mounting technique
    - ☑ Other BOS or installation characteristics
- ☒ Degree to which proposed system is representative of potential BIPV products

We were able to obtain five pre-engineered arrays (both of the 20kW single inverter systems and three of the multi-string arrays) while the remaining seven multi-string arrays were designed by project personnel to meet objectives approved by the TAC.

2.3.2.1.3 Deliverables

The following lists the deliverables that were specified for this task:

- ☒ DAS Letter of Notification
- ☒ Initial Characterization Reports

- ☑ System #1
- ☑ System #2
- ☑ System #3
- ☒ six-month Exposure and Operation Report
- ☒ Interim Report on Large Systems Progress
- ☒ twelve-month Exposure and Operation Report
- ☒ Consumer Confidence Guidelines for Large Systems

These deliverables comprise the documentation and results of the large system testing program. All of these documents were made available on both the project and program websites following Energy Commission approval (www.pierminigrid.org, www.pierminigrid.showdata.org).

Once the data acquisition equipment was specified, procured, and configured (prior to installation), the DAS Letter of Notification was submitted. Once each system was fully installed, commissioned, and operational, the Initial Characterization Report for that system was submitted. The Initial Characterization Report included the first draft of the PV System Test Procedure. This test procedure was refined throughout the project, and the final version was submitted with the Consumer Confidence Guidelines deliverables for small and large systems. That test procedure will be made available to a standards organization such as IEEE or the ASTM to be used as the basis for developing a standard.

After six months of data were collected, exposure and operation reports were prepared to update the project team and the Energy Commission on the results of the field performance evaluations. This was repeated after 12 months of data were collected.

An interim report on the progress of the large systems testing program was submitted as well, which looked at potential improvements to the performance index used to determine ongoing system health.

Finally, once the major lessons were identified and documented in this series of reports, researchers developed Consumer Confidence Guidelines to help prospective systems owners better choose a system that will meet their company's needs. These guidelines describe both the method of testing and evaluation used as well as the results from the systems under test.

2.3.2.2 Comprehensive Small System Comparison

The small system evaluation covered the selection, installation, operation, monitoring, and evaluation of three independent 2-kW PV systems. These systems were intended to indicate the kinds of PV hardware that an energy service provider would market to its residential and small commercial customers and also indicate hardware installed under the California Emerging Renewables Buydown Program. Over 2,000 systems like these had been installed in California by the time this project started, with little quantification of system quality or performance.

We selected pre-engineered systems (such as Sharp 2500, Kyocera MYGEN, and Schott Solar SunRoof) for this evaluation. No system designs by project personnel were needed to obtain a sufficient variety of systems for this evaluation.

2.3.2.2.1 Small System Site Selection

The small PV systems were co-located (at a single site) for fair and impartial comparison of the selected technologies. The site had an adequate installation area for three typical 2-kW residential roof-mounted PV systems (1,200 ft^2) along with associated power conditioning and monitoring equipment. The installation area has an unobstructed view to the east, south, and west.

The selected site for this activity was the EMT/SST area of the PVUSA site in Davis, CA. We were able to reach a cooperative agreement with Renewable Ventures to use the site and its facilities in exchange for engineering and operations assistance. The site is well characterized, has excellent solar resource, and was originally designed and built to test PV systems and components. We hosted one of the workshops at this facility.

2.3.2.2.2 Small System Selection

Small systems were selected by consensus of the TAC. The systems were nominally 2.0 kW (AC, PTC rating). We planned to select three systems total, including at least one incorporating battery storage and at least one without battery storage. Unfortunately, there were no pre-engineered grid-connected systems incorporating battery storage at the time of system procurement, and the TAC decided to avoid a custom system design at that point. System selection decisions included the following criteria:

- ☒ Price
- ☒ Supplier experience
- ☒ Degree to which proposed system meets program objectives
- ☒ Degree to which proposed system adds variety to project
    - ☑ At least one system incorporating battery storage (not feasible)
    - ☑ At least one system without battery storage

- ☑ Variety of modules
  - ☑ Variety of inverters
  - ☑ Mounting technique
- ☑ Other BOS or installation characteristics
- ☒ Degree to which proposed system is representative of potential BIPV products

The variety of modules actually being incorporated into pre-engineered systems was more narrow than anticipated. Given the wide variety that had been obtained in the large systems selection, preference for pre-engineered solutions was given over variety of components.

Not all of these systems fit the strict definition of "Building Integrated", which usually implies that the PV array takes on some function of a traditional building material (cladding, glazing, insulation, and so forth). Several of the systems—PowerLight Sloped PowerGuard, SIT, IES Solar Quilt—are intended to act as roofing material replacements or augmentation and do meet the purist definition. However, the number of suitable building material-type PV modules was very limited in 2003 when we were selecting systems, and even though the IEUA Headquarters was under construction, it would have been exceedingly difficult to try to architecturally integrate anything into the building since construction had already begun. Finally, by taking the roof-mounted approach, we were able to test a wider variety of the most commonly available products.

2.3.2.2.3 Deliverables

The following lists the deliverables that were specified for this task:

- ☒ DAS Letter of Notification
- ☒ Initial Characterization Reports
  - ☑ System #1
  - ☑ System #2
  - ☑ System #3
- ☒ Six-month Exposure and Operation Report
- ☒ Interim Report on Small Systems Progress
- ☒ Twelve-month Exposure and Operation Report
- ☒ Consumer Confidence Guidelines for Small Systems

These deliverables comprise the documentation and results of the small system testing program. Once the data acquisition equipment was specified, procured, and configured (prior to installation), the DAS Letter of Notification was submitted. Once each system was fully installed, commissioned, and operational, the Initial Characterization Report for that system was submitted. This Initial Characterization Report included the first draft of the PV System test procedure. This test procedure was refined throughout the project, and the final version was submitted with the Consumer Confidence Guidelines deliverables for small and large systems. That Test Procedure will be made available to a standards organization such as IEEE or the ASTM to be used as the basis for developing a standard.

After six months of data were collected, Exposure and Operation Reports were prepared to update the project team and the Commission on the results of the field performance evaluations. This was repeated after 12 months of data were collected.

An interim report on the progress of the large systems testing program was submitted as well, which looked at potential improvements to the performance index used to determine ongoing system health.

Finally, once the major lessons were identified and documented in this series of reports, researchers developed Consumers Confidence Guideline to help prospective systems owners better choose a system that will meet their needs. These guidelines describe both the method of testing and evaluation used as well as the results from the systems under test.

2.3.2.3 System Testing and Monitoring

System evaluation begins when the system is received, continues with information obtained from initial test results after system installation, and fills out with information obtained as the system operates. Combined, this body of information serves as the basis for a complete evaluation.

2.3.2.3.1 Documentation and Design Review

A complete system documentation package is essential to reproducible success in system installations. The documentation should be complete; it should provide information supporting safe and code-compliant electrical designs; it should describe applicable methods for the safe, secure, and durable attachment of PV arrays to the building structure; and it should detail critical installation and testing processes.

The detailed description of which elements were included in the documentation and design review are covered in detail in the Consumer Confidence Guidelines report. They included issues such as the following:

- System description and specifications.

- ☒ Parts and source lists for equipment supplied and not supplied with package.
- ☒ Electrical diagrams and schematics.
- ☒ Array installation guidelines and mechanical drawings.
- ☒ Installation and checkout procedures.
- ☒ Operation, maintenance and troubleshooting instructions.
- ☒ Owners manuals for individual major components.
- ☒ Information on how system performance monitoring is accomplished.
- ☒ Warranty information on components and complete system.

2.3.2.3.2 Installation Evaluation and Commissioning Testing

The installation review was designed to provide the installer with an understanding of key aspects of the installation. Challenges and difficulties were noted as well as installation aspects that were facilitated by good design and packaging. Key elements of this review addressed the following:

- ☒ Shipping
  - ☑ Special materials handling equipment for delivery?
  - ☑ Fragile?
- ☒ Array Installation
  - ☑ Worker-hours to install
  - ☑ Special skills
  - ☑ Special tools
  - ☑ Special safety considerations
  - ☑ Tests: FWRT, IV Array Curves
- ☒ Electrical BOS Installation
  - ☑ Worker-hours to install
  - ☑ Special skills
  - ☑ Special tools
  - ☑ Special safety considerations

The Field Wet Resistance Test (FWRT) and Array IV curve tests are described in the next section as special short term tests.

2.3.2.3.3 Performance Monitoring and Evaluation

The function of a PV system is to generate electricity. The amount of energy it generates relative to the size and cost of the system is of great interest to any PV system owner. This evaluation quantified the performance of the tested systems so that prospective PV system owners will be able to decide which product best suits their needs. The performance measures are categorized by whether special tests or long-term testing is needed to obtain the necessary information. For cost comparisons, our preferred data was the capital cost data provided by the manufacturer or as delineated in the bid. For those systems that were designed by project personnel, comparable estimates based on capital, worker-hours, and standard labor rates were used.

2.3.2.3.3.1 Special Test Results

Special tests are those that are performed to provide input on specific components and their operation that are relevant in the system evaluation. These tests were being performed over a few hours or days, and were being performed on components of the system rather than on the entire system as a whole or with the system operating in a particular mode.

2.3.2.3.3.1.1 Special Short-term tests

These short-term tests are generally accomplished with apparatus that is set up for a short duration. Examples of some special testing that was performed follow.

2.3.2.3.3.1.1.1 System Rating

The first concern of a new PV system owner is, "did I get what I paid for?" While energy delivered better defines "what I paid for", a key measure of system performance is the system-rated output power. Regardless of how well the stated rating matches actual system performance, this is the value used in most estimates of economic value. In addition, the ability to estimate the expected hours of "peak" (or at rated output) operation over a year provides a simple energy estimate for the system.

Each system installed under the project was rated according to the methods established by PVUSA, using data collected during the first interval of weather close to rating conditions. The researchers compared the value provided by the manufacturer and the rating established by the ERP. It is also the preferred value in all calculations that require system power rating.

2.3.2.3.3.1.1.2 Inverter Efficiency

The efficiency with which DC power is converted to AC power can vary due to several effects. Among these effects are output power level, input and output voltage, and the operating temperature of the power electronics (which depends on power level and ambient temperature). During each inverter's initial characterization, researchers evaluated each for efficiency over a range of conditions.

Annual inverter efficiency is a concept that is gaining support since it weights the effects of system design and low-irradiance performance on the overall conversion of PV energy into usable AC energy. Since this was a system-level evaluation, the annual or daily inverter efficiency is more valuable information than peak or 75% load efficiency (values which have been used by the Energy Commission Emerging Renewables Program for estimating the Energy Commission system rating for rebate purposes in the past). We compared the efficiency values from the initial characterization with those from long term testing and confirmed that the "weighted-average" inverter efficiency agrees more closely with annual measured inverter efficiency than the previous single-point measures did.

2.3.2.3.3.1.1.3 Inverter Maximum Power Point Tracking

Most inverters attempt to operate the PV array at the knee of the IV curve using a function called Maximum Power Point Tracking (MPPT). Using one of a variety of methods, these inverters attempt to determine the particular combination of voltage and current that yields the highest array output. The maximum power point varies throughout the day with changes in irradiance, temperature, and other factors. Traditionally, this impact has been neglected or characterized imprecisely. Some recent MPPT implementations have demonstrated a tendency to get "confused" and may operate the array off of its maximum power point for significant periods. Accurate evaluation of MPPT can be difficult, requiring specialized equipment. For this evaluation, MPPT characterization was primarily a function of the initial characterization. We also performed a rough field evaluation of MPPT function by measuring the variation in array efficiency with time as documented in the Small Systems Interim Report.

2.3.2.3.3.1.1.4 Array Efficiency

The efficiency with which solar irradiance is converted to dc power depends on the cell technology, the prevailing ambient weather conditions, and on how the inverter controls the dc operating point of the array. We used supplemental measures such as I-V curve results (operation independent of the inverter) and a detailed evaluation of the inverter's MPPT during laboratory testing to sort out the effects attributable to the module construction from those due to inverter function or malfunction. Once the system array efficiency was characterized and the nominal allocation of loss mechanisms was determined, we used to track long-term performance changes.

2.3.2.3.3.1.1.5 Field Wet Resistance Test

The Field Wet Resistance test (FWRT) ensures that the system has been manufactured, shipped, and assembled in a safe manner. This test, developed at PVUSA and described in [1], uncovers any breaches in the environmental seal protecting all components in the PV array, including module laminate materials, wiring, connectors, and junction boxes. These breaches are obviously a safety concern, but there are also serious reliability issues that arise from such problems.

In this test, a megohm meter is connected between the open-circuited or shorted array leads and ground. A mild surfactant (detergent) solution is sprayed on the array, the sheeting action of which tends to penetrate any voids or breaches in the environmental seal. If the surfactant solution is able to contact any of the current carrying conductors of the array, the megohm meter will indicate low impedance. The presence of these conductive paths may later be activated during rainy weather leading to corrosion (reduced reliability) or shock hazard (reduced safety). This test was conducted on all arrays after installation, identifying one marginal result with the Large Systems' APx-130 Solar Quilt array, and rodent damage to module interconnection cables for the Small Systems' Sharp ND-L3E1U array that occurred during or after installation.

2.3.2.3.3.1.2 Special Long-Term Tests

Other special tests use long-term data acquisition equipment that is put in place to make measurements over months or years. Examples of some special testing that was performed as part of this project follow.

2.3.2.3.3.1.2.1 Performance Index

Performance Index (PI) was developed by PVUSA [2] as a simple means for determining system health. The simplest definition for PI is the actual system output divided by the "expected" system output. Actual output may be defined either as instantaneous power or as accumulated energy over an arbitrary period. The strength of this measure is that it is a direct indication of system function with environmental conditions factored out. Its weakness is that the "expected" output model is valid only under fairly moderate environmental conditions. Extremes of irradiance or temperature can produce inaccurate results.

Power-based PI has proven to be very useful as a real-time performance meter, though for the reasons described above it tends to yield inaccurate results in the morning and evening. An alternative is to present power-based PI only during the middle four hours of the day or when the irradiance is above a nominal level. Daily energy-based PI will be presented so that the overall performance can be quickly viewed daily.

Extreme irradiance and temperature conditions correspond to relatively low fractions of the total long-term energy, so calculations averaged over the long term tend to be most accurate. We investigated possible improvements to the standard "expected energy" model used for the PI calculation as the primary subject of the Large Systems Interim Report and identified an approach for improving the consistency of daily (short term)

PI values at low load by adding a simplified model of inverter efficiency to the irradiance and temperature effects accounted for in the standard model.

For long term PI calculations, we ignored data from when the system experienced significant downtime due to external conditions.

The PI continued to demonstrate its value as an indicator of proper system function during this project. The PI is not a particularly valuable predictor of value for systems that have not yet been purchased, but it does provide a useful way to identify performance issues as they occur, to prevent system malfunctions from persisting over long periods.

2.3.2.3.3.1.2.2 Energy Capture

This value measures how much of the available radiant energy the system was prepared to accept. This value is weighted based on the time of day that the inverter is not operating. It is expected that the unit be off during night hours, but it is expected to be on during daylight hours. Should the system start later in the morning than another system, the effect on performance may be small compared to an outage at noon. This is distinct from how much it actually transferred to the grid or battery storage and can be used to distinguish excessive downtime from excessive losses while operating. The weakness of this measure is that it depends on the existence of an "inverter operating" status signal that is rarely present on commercial inverters. For this project, the "inverter operating" signal was synthesized by using a small, positive, nonzero threshold AC output power value (100 W) to indicate "on" status. This can help determine how much of the time the system was available and producing power.
In practice, we found the usefulness of this measure to be minimal compared with that of the PI measure.

2.3.2.3.3.2 Energy Performance Testing Results

Energy is a common basis for evaluating long-term system performance. A weakness of this measure is that it is specific to the attributes (size, components, and so forth), location, and prevailing weather conditions of the system tested. Energy output normalized by array size or rated power for co-located systems provides for more relevant comparisons.

2.3.2.3.3.2.1 Energy per area per year

This measure describes the value of the system on the basis of array area, assuming a consistent definition of array area is defined for all systems. In many cases, limited space is available for system installation, and this is a useful measure for constrained space locations.

While actual footprint area required for the whole array is a desired result of preliminary system designs, this value may vary considerably based on site-specific concerns. For this reason, we have concluded that the sum of module areas is an easily calculated reference for annual energy per area, while the ratio of the footprint area to the sum of module areas can be used to account separately for the array-packing density.

2.3.2.3.3.2.2 Energy per rated power (Yield)

Energy as a function of array capacity (STC power rating) or system capacity (PTC power rating) is useful for comparing the operational characteristics of co-located systems. PTC-based yield values were computed using daily, monthly, and annual energy and the AC PTC output rating established for the system after installation. For comparison, versions of the yield based on STC power ratings were also computed and demonstrated large uncertainties due to manufacturer production binning and uncertainty in temperature coefficients.

This measure is useful for preliminary system design because it establishes a link between energy production (return on investment) with power rating (which drives capital costs). Unfortunately, prior to purchase, the designer has manufacturer specifications to work with that are based primarily on STC power rating, so the accuracy of pre-installation estimates of energy production will be limited by the uncertainty in the actual (PTC) system power rating. (Note that Energy Commission estimates of system power rating are based on STC ratings, so while the magnitude of a Energy Commission rating may be similar to the magnitude of the actual PTC rating, the Energy Commission rating is just as likely to predict energy production incorrectly as the STC rating is.)

2.3.3 Data Collection, Reporting, and Technology Transfer

Data collection encompasses the sampling and manipulation of the information needed to evaluate the PV systems per the goals of this project. Data reporting for this project included various steps to transform the raw data into understandable information. Key features of these processes included:

- Accessibility of data through internet access (both public and password protected).
- Graphical presentation of data on Web.
- Archiving data for project record and later detailed analysis.
- Paper reports including initial characterization, interim and final reports, and a consumer confidence guideline report.

2.3.3.1 Data Acquisition Plan

Data acquisition encompasses the sensor, wiring, digitization, and initial aggregation (average, maximum, and so forth), as well as transmission to the central data repository.

2.3.3.1.1 Data Collection Procedures

Data collection was conducted using both automated and manual methods. Data collected for use in the initial characterization reports included component-level evaluations using laboratory test equipment. Exposure and operation reports depended primarily on datalogger-based hardware (described below), supplemented with periodic field tests to check component function as needed.

Automated data collection procedures included sampling at 5-second intervals (1 second for the Small Systems' DAS, due to fewer channels) and statistical aggregation of samples over 15 minute intervals for recording. The aggregation interval for the Large Systems' DAS was changed for one week in mid-July 2004 to 1 minute to stress test the DAS and then switched to 5 minute samples for the remainder of the test period.

Data was automatically transferred to a central data repository at 15-minute intervals. As often as this data became available (subject to Internet communication delays), it was automatically processed to remove obviously erroneous data, and both raw and summary data were transferred to an Internet Web server for storage in a server-side SQL database. Data was also accessible via links from Microsoft Access databases to support ad-hoc data evaluation by an analyst for the generation of exposure and operation reports.

2.3.3.1.2 Function

The data acquisition system included the following characteristics:

- Recording of parameters at appropriate accuracy.
    - AC real power at inverter-grid connection point
    - AC voltage
    - DC voltage and current (for a subset of systems)
    - Ambient and array temperature
    - Irradiance: plane-of-array
    - Wind speed
- Statistical data volume reduction (average, maximum, minimum).
- Computation of nonlinear equations (power, modeled power) before averaging.
- Buffering of data to minimize effect of any communications disruptions.

2.3.3.1.3 Hardware

The reference data acquisition platform was a Campbell Scientific CR23X datalogger, which has a variety of analog and pulse input capabilities that are appropriate for this application. The datalogger was augmented with pulse-output energy meters and true RMS voltage[4] transducers for monitoring AC power production, and voltage transducers and current shunts/isolators for PV array monitoring. Weather was monitored with silicon pyranometers and a thermistor for air temperature. Type T thermocouples were used for monitoring the array temperatures. Data was sampled at least every 5 seconds and aggregated over 1-, 5- or 15-[5] minute intervals to reduce buffer storage requirements compared to storing every sample.

The reference DAS would have been a costly solution for monitoring 10 string inverters, so (per our plan) we monitored one set of DC and AC measurements for each of the three large systems and relied on monitoring by direct communication with the string inverters (via the SMA Sunny Boy Control data recorder) to complete the suite of measurements. (For the small systems, all DC voltage and current readings were measured with the reference DAS.) By comparing the results from the string inverters that are instrumented with the reference DAS, we quantified the accuracy of the string inverters' internal monitoring capabilities. The DC voltage readings were 1.4% low around midday, and the current readings were about 1% low around midday. Near sunrise and sunset, both the absolute and relative errors for voltage and current increased considerably, and no inverter data were available at night. AC power data absolute errors also exhibited a dependence on power level, ranging from 4% low (relative) at low power to 0.4% high (relative) at full power. We concluded that in this case the inverter-based monitoring accuracies were sufficient for most troubleshooting purposes but were not appropriate for use in computing inverter or array efficiency estimates for comparing technologies.

Fortunately, both the large systems and small systems evaluation sites were equipped with Ethernet-based internet communication facilities and indoor space for installing a low-cost PC to handle data transfers. Lacking the Ethernet option, a telephone line

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[4] RMS voltage can adversely affect inverter efficiency, and out-of-spec voltage can trigger inverter disconnects. The inclusion of RMS voltage measurement is intended to support troubleshooting of possible intermittent variations in inverter operation.

[5] While 10-minute recording intervals were planned to be consistent with the PVUSA data set, 15-minute intervals are more typical for weather monitoring and utility demand metering. Five minute intervals were requested by Sandia as part of a data compatibility effort, since 5-minute intervals can be used to calculate either 10-minute or 15-minute aggregations during post-processing.

connection would have been used for such data transfers and to support remote access to the computer for maintenance.

2.3.3.1.4 Software

We monitored the reference DAS and downloaded data to CSV files using the PC208W software written by Campbell Scientific. Data handling scripts were written to send this data as email attachments to the central data handling computer, and additional scripts were written to retrieve the email, load the data into a relational database management system (SQL Server), and compute daily summary results. Finally, after data were summarized, a screened data update was transferred to the pierminigrid.showdata.org Web data display system. All scripts were written in Perl (Activestate) and Bourne shell (Cygwin) as batch processing tools.

Remote access to the Large Systems' data collection computer for maintenance was implemented via Laplink Gold through a virtual private network. Laplink Gold provides similar functionality to the PCAnywhere solution that was originally planned. No remote access was necessary for maintenance of the Small Systems' data collection computer, since two of the project personnel lived within minutes of that site.
The Web server was implemented with Cold Fusion MX to simplify presentation of interactive forms, augmented with Java servlets to generate the graphs on the fly using data stored in a SQL Server database.

A Microsoft Access database file (pierdb_review.mdb) was created to provide a convenient user interface for invoking both predefined and ad-hoc SQL queries on the central SQL Server data repository. This was the primary source of data for reports, while the web server was primarily used as a real-time status display for PV system operation.

2.3.3.2 Data Evaluation and Reporting

We evaluated exposure data by reviewing graphical and tabular summaries generated via the Microsoft Access database. The graphical summaries consist primarily of time-series plots of weather and measured system variables such as voltage and output power. Tabular summaries consisted primarily of aggregate energy, energy per unit area, energy per unit rating, performance index, energy delivered, system efficiency, yield, and irradiation. Energy capture was found not to provide significant benefit when compared to the PI value and was not emphasized.

These exposure data were presented in reports and presentations along with the results of the component characterization tests, documentation/design reviews, and installation and commissioning results, to allow interested parties to evaluate the relative strengths and weaknesses of the systems. All system evaluations were presented in terms of significant strengths and weaknesses of a particular design, as the intended use of a particular system may warrant tolerance of poor evaluation results in some areas in exchange for specific features, and such decisions must be made in a case-by-case basis.

2.3.3.2.1 Automated Queries

SQL was used extensively to compute statistical quantities and derived measures described previously. The SQL language supports the use of "null" (unknown) values, allowing intermediate calculations to filter "known-bad" data and compute results based only on the remaining data. To obtain "sensible" results with null data, these computations require careful construction to avoid confounded results. For example, invalid/missing weather data could cause a shortfall in the expected energy portion of the performance index, causing a misleading increase in performance index. We applied the techniques used in the PVUSA performance database to minimize the effects of such data anomalies by discarding all inputs to the calculation for times when one of the necessary values was not valid. Where feasible, data that was invalid or not representative of the operation of the system (for example, utility outages, special tests) were replaced with estimated data.

2.3.3.2.2 Ad Hoc Queries

The need for ad hoc data evaluation arises when standard data summaries do not directly show the nature of some phenomenon of the system operation. For example, an inverter that self-limits power conversion at high temperatures may show "erratic" daily performance index values. When power output is plotted against temperature instead of time, this relationship will become clear. The activity of ad-hoc data evaluation consists of this interactive extraction and plotting of data in response to theories of operation. Since the exact nature of the unusual behavior is not known beforehand, the availability of a flexible data extraction and review system is a valuable resource for characterizing PV systems.

The standard tools used by BEW Engineering for this analysis were Microsoft Access for formulating and executing data selection queries and Excel for plotting and applying hypothesized models to data. Data for this project were extracted using Access primarily from a SQL Server database that could handle the simultaneous load of processing incoming data every 15 minutes as well as handle ad-hoc queries.

2.3.3.3 Technology Transfer

A key element of any research project is the plan for disseminating results. This project used "real-time" (every quarter-hour) Web data presentation to provide transparency into the system evaluation, as well as using the standard practices of publication of technical reports, conference papers, and workshops.

2.3.3.3.1 Web Presentation

The initial Web page design was based in large part on the information defined in the test plan document. Web page updates were made for all the systems as they began operation. Technical papers and the presentations of that material summarizing results of findings in the reports and ongoing system monitoring were posted on the webpage. Workshops were scheduled and presented after significant findings were published and made available.

A PV System Evaluation website was developed to present the status and results from the project. The project's pierminigrid.showdata.org website was directly linked from key locations in the program website (www.pierminigrid.org). The project website includes pages that provide the following information:

- Project description – Describes the goals of the project, the scope and purpose, participants, and how the project fits in both the Commerce Biogas/PV Renewable Mini-grid Program and the California Energy Commission PIER program.
- Static System Information – This section provides a detailed description of each system under test. Information includes description of major components and key features, manufacturer's rating, and installed system rating.
- Performance Data –Includes both historic and "Real time" (updated every 15 minutes) graphically presented information, available to the public.
- Tech Transfer – This section includes references to workshops, papers, presentations, and reports after they are accepted as final by the Energy Commission.
- Restricted Access pages – No need for password protected portions of the site was identified.

No sign-up system for notifications regarding website changes was implemented because the Google Alerts service (http://www.google.com/alerts) was determined to provide a reasonable equivalent service at no charge. This feature was not requested by any participants.

2.3.3.3.2 Technical Papers/Presentations

Per our plan, we developed two project presentations. The first was presented at the 2003 ASES conference and again (slightly modified) at the 2003 Sandia System Symposium. The second presentation was given at the 2005 ASES conference.

2.3.3.3.3 Workshops

After the designated evaluation periods were finished, a set of workshop materials was developed and a series of three workshops was conducted using those materials to provide consumers and installers with guidance on PV system selection, design and installation using test results from the evaluation testing. Workshops were conducted at working PV installations (one each at the small and large systems evaluation sites, and one at the Sacramento Municipal Utility District's Hedge Substation solar installation) to allow workshop participants to see examples of actual PV system implementations. Data from the evaluations were presented and discussed during the workshops. Each workshop covered a three-day period and attendees were to be charged more than $100 per day. However, to increase attendance, the original plan for four workshops was reduced to three, and budget was allocated to subsidize attendee costs for a final cost of approximately $25 per day for the second and third workshops.

In addition to the public workshops, a short workshop on PV system design, installation, and maintenance was conducted for the IEUA maintenance electricians when the large PV systems were installed. The presence of this pool of trained personnel has shortened MTTR on those PV systems, benefiting Inland Empire Utility Agency (IEUA) and Commerce Energy.

3. Project Outcomes

Figure 4 Large System Evaluation at IEUA Headquarters, Chino, CA

The following sections describe what actions were taken and what was achieved in the project. The first two subsections provide high level discussion of project achievements. Successive subsections drill further down into details of specific issues.

3.1 Key Technical Results

Over the course of this project, a number of key results were achieved. The list below highlights a few of these key results.

The program Web page—www.pierminigrid.org—and the project Web page—www.pierminigrid.showdata.org—provide access to all project reports and presentations referred to in this report

- Installed and evaluated 15 Systems representing.
    - 9 Cell technologies
    - 10 module manufacturers
    - 4 system integrators
    - 3 inverter manufacturers
    - 7 mounting methods
- Prepared magazine-style presentations of system evaluations.
- Refined and documented system evaluation methodologies.
- Prepared reports covering 6-month and 12-month performance for the both the large and small systems.
- Provided detailed comparison of different module and system ratings.
    - Evaluated appropriateness of STC, the Energy Commission, and PTC ratings.
    - Evaluated how well each system met stated ratings.
- Created and maintained an interactive web presence.
- Trained 170 installers and other interested parties in three-day advanced PV workshops.
- Helped inverter manufacturer identify and repair two control system software anomalies.
- Discovered that rodents like the taste of PV module electrical connectors.
- Helped PVUSA site owner diagnose and repair a failure in the 480 V circuit supplying the small systems
- Supported the development of the Sandia Inverter Test Protocol by
    - Providing test specimens and assisting in testing/procedure development.
    - Providing field data.
    - Attempting to evaluate MPPT in the field.
- Defined improvements to the performance index
- Assisted in the development of an energy purchase/system purchase agreement between Commerce Energy and Inland Empire Utility Agency and facilitated obtaining SGIP rebate.

3.2 Meeting the Goals and Objectives

The Building Integrated PV Testing and Evaluation Project achieved nearly every goal and objective stated in the original contract:

- Address the gap between future third-party certified PV component and system performance results and currently available information from manufacturers

- As previously shown, the systems tested under this project represent a broad cross section of cell technologies, module and inverter manufacturers, on-roof mounting systems, and system integrators. This review has identified areas of component and system performance that should help regulators define necessary testing and inform manufacturers and system integrators where to focus their product development efforts.

- Provide an independent comparative evaluation of PV systems critical to Project 3.3 and to the ERP Rebate Program.

    - Twelve commercial and 3 residential PV systems were evaluated and compared regarding installer concerns, component performance, system performance, and cost.

- Provide decision-making information on those PV systems.

    - Tabular and graphical performance and cost data have been compiled, and guidance on interpretation of these data has been provided.

- Improve the quality of systems installed in Project 3.3 through directed training.

    - Though Project 3.3 was prematurely stopped, the intended workshops were given, and almost 170 installers and other interested parties throughout the state received training. The original concept was to use PIER funding to cover a portion of the basic labor costs and fund the remaining costs through an attendance fee. After attending the first workshop, PIER contract manager Zhiqin Zhang proposed that the PIER funding be redirected to cover enough of the workshop costs to reduce or eliminate the attendance fee to encourage a much higher attendance. While less than 10 people attended the first workshop (held in Northern California at the PVUSA Davis site), attendance at the next two was 90 (Northern California at SMUD Hedge Substation) and 70 (Southern California at the IEUA Large Systems evaluation site).

- Select, procure, install, and evaluate three candidate PV Systems for implementing Project 3.3 BIPV on public buildings (and repeat for three small residential-scale systems)

Three 20-kW commercial-scale systems ("large") were installed at the IEUA Headquarters building in Chino California. One of the large systems comprises a 10-segment array, giving data for 10 module types and providing an opportunity to evaluate a system implemented with multiple identical inverters. In reality, each of the 10 segments was evaluated as a separate system, providing four times more information than originally projected for the large segment. The cost of these systems was covered by Commerce Energy and will be recovered through a power purchase agreement with IEUA. In addition, three residential-scale systems were installed at the PVUSA site in Davis, California. These systems were offered on-loan from the manufacturers for the duration of the testing period.

Table 2 System Descriptions

Site	Integrator	Module	Tech	Inverter	Mount	Ratings			
						PTC (kW)	CEC (kW)	STC (kW)	PTC/ STC
IEUA, Chino, CA	PowerLight	Sanyo HIP-190BA2	HIT	Xantrex PV20-208	Sloped PG	17.97	20.59	22.80	0.81
	Schott Solar	Schott 300-DGF/50	EFG		SunRf FS	18.52	20.67	24.00	0.77
	IES	UniSolar US-116	a-Si	SMA SWR 2500U	Quilt	1.86	2.07	2.32	0.80
	SIT	UniSolar PVL-128	a-Si		SIT	1.89	2.05	2.30	0.82
	N/A	Shell Solar ST40	CIS		Custom	2.13	1.99	2.40	0.89
	First Solar	First Solar FS-45	CdTe		EZ Mount	2.10	2.17	2.43	0.78
	IES	AstroPower APx-130	pc-Film		Quilt	1.63	2.11	2.73	0.60
	N/A	Evergreen EC-102	SR-pc		Custom	1.90	2.06	2.45	0.78
	N/A	BP Solar SX-140	pc-Si		Custom	1.95	2.09	2.52	0.81
	N/A	Schott SAPC-123	pc-Si		Custom	1.94	2.03	2.46	0.79
	N/A	Shell Solar SP140	mc-Si		Custom	2.02	2.13	2.52	0.80
	N/A	AstroPower AP-110	mc-Si		Custom	1.95	2.09	2.40	0.81
PVUSA, Davis, CA	Sharp	Sharp ND-123U1	pc-Si	Sharp JH-3500U	SolarMount	2.30	2.38	2.95	0.78
	Kyocera	Kyocera KC167G	pc-Si	SMA SWR 2500U	SolarMount	2.01	2.11	2.51	0.80
	Schott Solar	Sharp SAPC-165	pc-Si		SolarMount	2.40	2.45	2.97	0.81
	TOTAL					62.6	69.2	80.0	0.79

Technology:
HIT: Mono-Crystalline Silicon surrounded by thin Amorphous Silicon layer
EFG: Edge-defined Film-fed Growth Poly-Crystalline Silicon
a-Si: Triple-Junction Amorphous Silicon
CIS: Copper Indium Diselenide
CdTe: Cadmium Sulfide/Cadmium Telluride
pc-Film: Poly-Crystalline Silicon Film
SR-pc: String Ribbon Poly-Crystalline Silicon
pc-Si: Poly-Crystalline Silicon
mc-Si: Mono-Crystalline Silicon

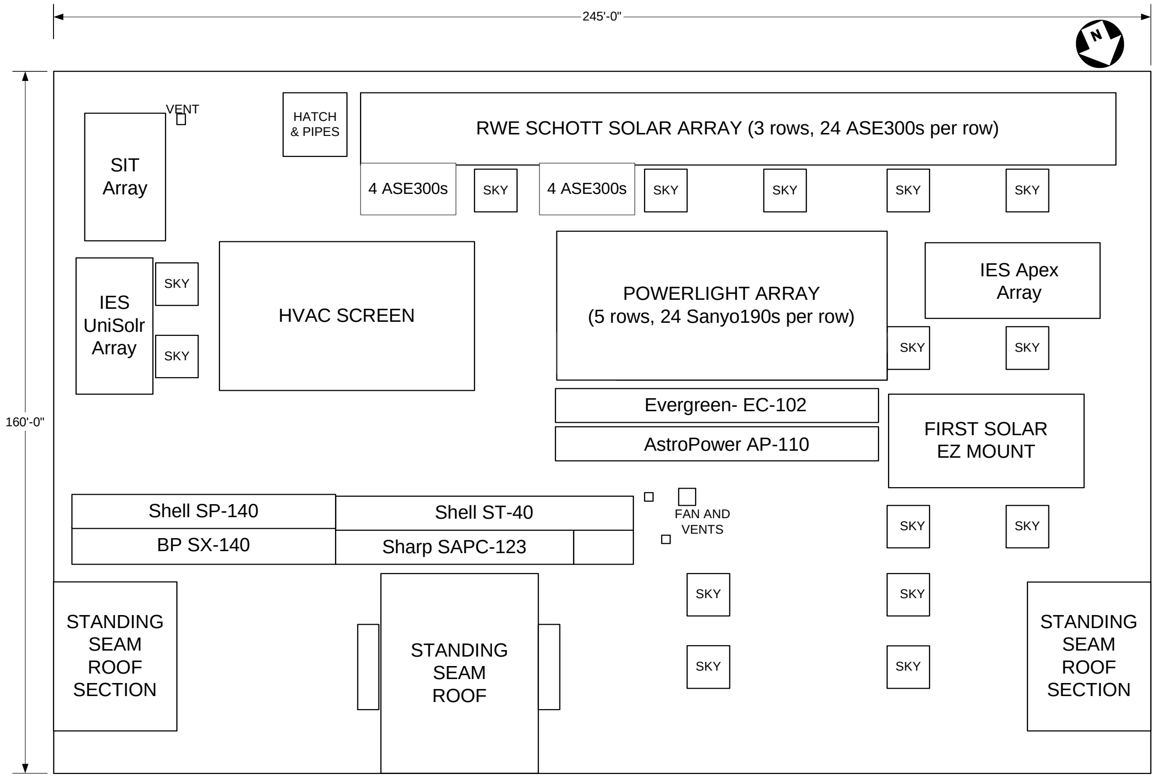

Figure 5 Layout of PV Systems on IEUA Headquarters Rooftop

Figure 6 **Residential "Small" Systems at PVUSA (Top: Schott SunRoof RS2500 with other two systems to the left; Middle: Kyocera MyGen 2500; Bottom: Sharp System**

- Determine flaws, weak points, poor design features, and so forth, and offer suggested fixes.
  The design and installation of each system installed was described in the system characterization reports (www.pierminigrid.showdata.org/docs.cfm), and ongoing issues with operation were described in interim, 6-month, and 12-month reports. Some specific issues were identified as follows.

  1) Providing consistent solar access to all PV systems.

  One of the early lessons related to the difficulty of laying out multiple systems on the "flat" commercial rooftop so that systems have the same access to the solar resource. As it turns out, flat commercial roofs have a 2-4 degree roof tilt angle for drainage that is enough to cause a few percent difference in solar resource from one part of a flat roof to another. Note that this roof tilt can be in any direction, meaning it can enhance or detract from the PV array structure tilt or it can cause the array to slightly favor the morning or afternoon sun, and all of these options were in effect on the IEUA building. The other challenge is staying clear of rooftop obstructions. The roof has a parapet wall that varies in height from 1-4 feet, an HVAC shroud that is over 9 feet tall, and numerous skylights that allow for few fully open spaces on the 32,000-square-foot roof surface. As a result, minor shading was experienced on many of the systems. Even though the roof had more than twice the roof surface to mount the arrays, the actual unshaded surface was nearly completely used. This shading was constrained to early mornings or late afternoons on most systems. A few systems experienced more shading in late December and early January due to the low sun angle. These experiences are common in commercial construction. In fact, it could have been worse: IEUA moved the HVAC shroud away from the normal center-of-the-roof location to better accommodate PV on the roof.

2) Xantrex MPPT

As originally received, the control software in the Xantrex PV20-208 was not optimized to work with Sanyo HIT technology, which exhibits a higher than typical array capacitance and a high fill factor causing the array to routinely provide a higher voltage than the inverter was designed to track. The effective capacitance of the array impacts how the array responds to step changes in operating voltage and must be accounted for when the inverter is maximum power point tracking. In addition, the inverter had trouble finding MPPT whenever the array maximum power voltage exceeded 400 V (a condition that occurs most of the year), characterized by wide swings in array voltage. These problems had not been noticed in other systems in part because of the transient nature of the event, and in part because, apparently, those systems were not monitoring array voltage, relying only on ac energy meters to provide system performance. Over the course of several site visits, Xantrex personnel were able to diagnose and correct the problem as of May 2004.

3) SMA inverters not getting sufficient air flow

The inverter room did not have sufficient cooling the handle the heat load of the inverters with the door closed. During the week, the door to the room remained open, and the inverters remained cool. On weekends when the door was closed, the SMA inverters would limit power during the middle of sunny days. A floor fan placed in the room to circulate air solved this problem. Additional air circulation is intended to be added to the adjacent computer room, which, due to the computer load, also runs hotter than desired. This additional air circulation will be exhausted through the inverter room for additional cooling there as well.

4) Xantrex voltage trip window

Utility-connected distributed resources must "cease to energize" the utility when any line to neutral voltage goes outside of a ±10% window around the nominal voltage. With its delta transformer connection, the PV20-208 measures line-to-line voltage and therefore must trip within a narrower ±6% window to account for a possible single-phase voltage reduction or increase. Under the more common three phase voltage drop or rise, the inverter will operate much more conservatively than a unit measuring the line to neutral voltages. Tied to a service panel well inside the IEUA headquarters building, the large systems are subject to the normal utility variations in voltage as well as building load-induced changes. The result was that the unit experienced more frequent under- and over-voltage trips. This was eventually corrected by asking the utility to allow wider than normal trip settings, which they did. Following many of these voltage trips, the unit locked itself out and would not automatically restart when the voltage came back into spec. This was also corrected with a software fix.

5) APex high temperature/low voltage

So as not to exceed the inverter maximum power limit at low temperatures, the AstroPower APex array was designed by the project team as a single string of 20 modules in series, which created a potential low voltage concern at high temperatures. The system was mounted using the IES Solar Quilt mounting system that had an untested impact on module operating temperature. The operating temperature turned out to be substantially higher than expected (See Figure 7). This graph shows that the APex system approaches a 55 °C temperature rise above ambient at 1000 W/m^2 compared with the 30°C or so rise of the PowerLight array (thus at 20°C ambient and 1000 W/m^2, the arrays would be at 75°C and 50°C, respectively). As temperature rises, the array max power voltage drops and at peak irradiance conditions (i.e., > 800 W/m^2), the APex array maximum power voltage would drop below the inverter's minimum operating voltage, causing an even steeper decline in output vs. temperature. The situation was probably exacerbated by the fact that, like all the other systems, the modules were delivered with power and voltage characteristics below specification. The result is an inappropriate system rating because at peak irradiance, the array was not at maximum power.

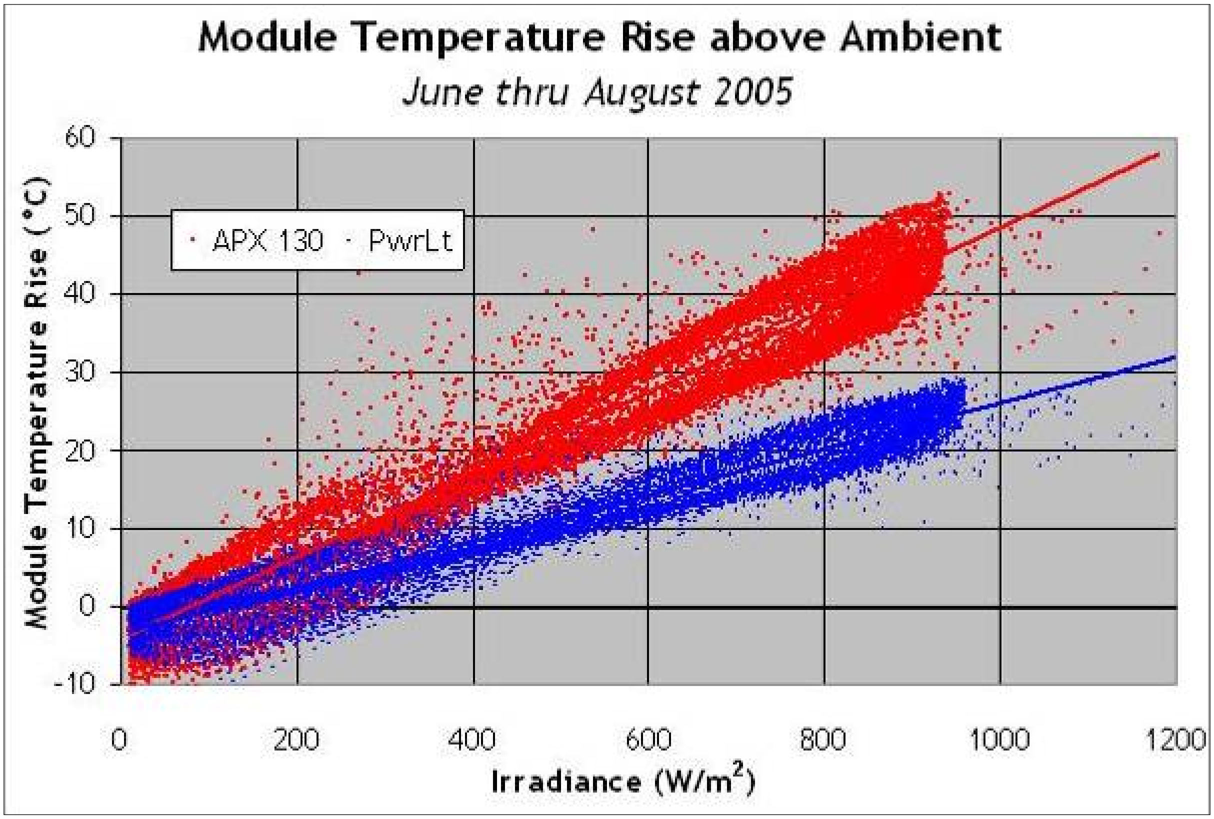

Figure 7 **Temperature comparison of APX130 (upper, red) and PowerLight (lower, blue). The loop shape for each array is caused by the thermal mass related delay in response to changes in irradiance (lower part of loop in morning, upper part in afternoon). The upper part of the loop at high irradiance better represents steady state temperature at those conditions, so one should expect higher temperatures than are indicated by the linear trend lines provided for each**

6) Rodent chewing plug connectors

We made an interesting discovery with the small systems during installation at the PVUSA site. One night while the installation of the Kyocera system was in process, rabbits got into the system wiring and chewed the MC connectors off the panel interconnect wires. This was the first indication that the project team had that the MC connectors do not have rodent-inhibiting compounds in their rubber. This is of particular concern given the likelihood of squirrels, rabbits' close relative, chewing on these connectors that are installed in more than 10,000 systems in California.

- Evaluate selection, ease of installation, performance, other issues that may affect life-cycle costs

These issues are address in great detail in the Initial Characterization Reports (an example of which is summarized in section 3.3.2.1).

- Monitor and report on system performance for 12 months

  Installation of the large systems was completed in October 2003, and final approval to interconnect was received February 26, 2004. System operation and monitoring began on March 1, 2004. Installation of the Small systems was completed and the systems energized in May 2004. The starting date for operation and monitoring was June 1, 2004. Six month and 12-month operation reports detail the performance results for both sets of systems.

  Most presentations of simple PV economics and performance normalize the installed cost to $/kW and the annual energy production to kWh/kW often using a system rating based on the aggregate module dc rating at Standard Test Conditions (STC). The ERP has already taken the first step towards the use of more realistic ratings by converting the traditional STC module rating to PTC, which better represent peak conditions in the field. While for some, this seems a step in the wrong direction—since the PTC rating for a given system is lower than the STC rating, the $/kW frustratingly increase—it does provide a rating that more closely resembles actual system performance. However while the ERP rating ("the Energy Commission" in this project) addresses the module temperature issue and also includes a measure of inverter efficiency, it does not address a number of other system losses including wiring, mismatch, and module rating.

Table 3 Summary of Small System Efficiencies and Ratings

Array	Manufacturer	Model	Mount	Area	Eff_{SYS}	$Rating_{PTC}$	$Rating_{CEC}$	$Rating_{STC}$	PTC/STC
				sq. m.	%	kW	kW	kW	rating ratio
Sharp	Sharp	ND-123U1	SolarMount	33.8	6.80	2.30	2.38	2.95	0.78
Kyocera	Kyocera	KC167G	SolarMount	30.2	6.66	2.01	2.11	2.51	0.80
RWE/Schott	RWE/Schott	SAPC-165	SolarMount	29.2	8.22	2.40	2.45	2.97	0.81
TOT				93.2	7.20	6.7	6.9	8.4	0.80

Table 4 Summary of Large System Performance Index and Energy Production

Array	Manufacturer	Model	Tech	Mount	P_{STC} kW	P_{PTC} kW	PTC/STC rating ratio	P.I. %	Energy* kWh
PL	Sanyo	HIP-190BA2	HIT	Sloped PG	22.80	17.97	0.79	92	31101
RWE	RWE/Schott	300-DGF/50	EFG	SunRf FS	24.00	18.52	0.77	92	31126
3A	UniSolar	US-116	3-a-Si	Quilt	2.32	1.86	0.80	96	3173
3B	UniSolar	PVL-128	3-a-Si	SIT	2.30	1.89	0.82	102	3384
3C	Shell Solar	ST40	CIS	Custom	2.40	2.13	0.89	94	3651
3D	First Solar	FS-45	CdTe	EZ Mount	2.43	2.10	0.86	101	3620
3E	AstroPower	APx-130	pc-Film	Quilt	2.73	1.63	0.60	97	3006
3F	Evergreen	EC-102	SR-pc	Custom	2.45	1.90	0.78	100	3182
3G	BP Solar	SX-140	pc-Si	Custom	2.52	1.95	0.77	97	3379
3H	RWE/Schott	SAPC-123	pc-Si	Custom	2.46	1.94	0.79	97	3361
3I	Shell Solar	SP140	mc-Si	Custom	2.52	2.02	0.80	101	3414
3J	AstroPower	AP-110	mc-Si	Custom	2.40	1.83	0.76	94	3081
Total					**71.3**	**55.7**	**0.78**	**94**	**95478**

* Energy reported here for the PL and RWE systems is adjusted for a two-week inverter malfunction so that energy output from all systems are comparable.

- Develop recommendations for system purchases.

  A key goal of this project was to provide system purchase recommendations for the other Commerce Energy PV-related project, Project 3.3 BIPV on Public Facilities. That project intended to *"…demonstrate the potential for taking advantage of affordability improvements and valu- added applications by demonstrating a number of new and repeatable project development approaches in public facilities with relatively large building integrated PV systems."*

Unfortunately, that project did not proceed past the initial development stage, so there were no recommendations made. While the Consumer Confidence Guideline provides rankings for the systems under review, without knowledge of the particular project, and the details of the building design, and the needs and wants of the customer, it is inappropriate to make a blanket recommendation.

3.3 Details of Key Outcomes

The following sections look at a few key outcomes in greater detail.

3.3.1 System Ratings

The first concern of a new PV system owner is, "Did I get what I paid for?" While the amount of annual and (projected) lifetime energy delivered best defines "what I paid for," a key measure of system performance is the system-rated output power under a specific combination of reference conditions. Regardless of how well the advertised rating matches actual system performance, and despite the increasing use of performance/energy-based economics, rated output power is still the value used most often in economic calculations in the United States (for example, the ERP Rebate administered by the Energy Commission: www.consumerenergycenter.org/erprebate). Economic analyses based on system rated power are only as accurate or as flawed as the methods used to determine the rating. In addition, if the system is accurately rated at conditions that are indicative of peak conditions for the installation, then the estimate of the expected hours of "peak" (or at rated output) operation over a year provides an accurate simple energy estimate for the system.

Standard Test Conditions (STC) were originally defined to provide PV cell developers and test agencies with a set of conditions convenient for laboratory testing. Unfortunately, those conditions are rarely encountered in the field. Nevertheless, STC is still used as boilerplate rating for PV modules, and system ratings are still often expressed as the simple product of the module STC DC rating and the number of modules. As the vast majority of systems 1) operate at temperatures significantly hotter than STC and 2) provide the owner with ac power (which is always less than DC power due to inverter losses), using the common STC DC rating this way is the practical equivalent of selling Honda generators based on the horsepower rating of the engine driving the generator. While engine horsepower is an important parameter and is related to the AC electrical power that the generator package will provide, the customer is much better served by having a primary device rating that is a direct measure of the quantity that the customer expects the unit to provide: in this case, AC electrical power. STC ratings also provide a less consistently predictable starting point for estimating energy production since STC module ratings include potentially large uncertainties due to manufacturing tolerances.

In the late 1980s, the PVUSA project (a utility-led effort to clarify the technical and contractual issues related to investments in grid-connected PV) identified "good" operating conditions for power production in the field. Each system installed under this project has had its power output rated under these PVUSA Test Conditions (PTC). This AC rating ($Rating_{PTC}$ in **Table 8** of large and **Table 9** of small systems sections) may be compared to the DC value provided by the manufacturer ($Rating_{STC}$, the simple sum of module STC ratings) and to the AC rating established by the Emerging Renewable Rebate program ($Rating_{CEC}$).

The STC and the Energy Commission rating methods are not accurate indicators of field performance and tend to over predict instantaneous performance by 10-20%. There are three reasons why the PTC_{AC} rating is favored for predicting system performance [3, 4]. First, the PTC_{AC} rating represents actual measured performance of the system. The STC and the Energy Commission ratings are based on manufacturers' published module data. It is an unfortunate but widely known fact that manufacturers that have provided conservative module ratings in the past have lost market share because doing so inflates their $/$W_{STC}$ cost. To date, the U.S. market has tended to respond better to lower $/watt even though the ratio of $watt_{received}$/$watt_{claimed}$ rarely approaches 1.0. This situation can be changed by several methods:

- Require third-party evaluation/certification of module performance. PowerMark, for example, provides this sort of certification process, and there are at least two labs that are accredited for performing PowerMark ratings. Modules sold into the Florida market must be PowerMark rated. Though the small number of modules evaluated in the PowerMark rating can lead to a relatively high uncertainty, a requirement for third-party rated PV modules would be consistent with the recent change in the ERP Program to require third-party performance testing of inverters. This approach places the rating requirements on the module manufacturer and only addresses module rating.
- Buy system based on installed AC watts, as has been done by PVUSA, Sacramento Municipal Utility District (SMUD), Utility Photovoltaic Group (UPVG), and other large procurements. This approach allows for all of the system power losses but does not address issues that might improve or reduce energy production, such as dust, shading, or mechanical tracking (which increases energy production but is of no value in system rating). The installed watts method puts the pressure on the system installers/providers to make sure they either have good data from the manufacturers or apply their own conservative loss-factor estimates to account for effects such as wiring resistance, mismatch, sub-nameplate average module power, and initial light-induced degradation. Verifying installed watts on a system-by-system basis is expensive and primarily suitable for larger systems. Third-party-type characterization can be performed on small packaged systems (as is being done under the small systems evaluation of this project).
- Buy systems based on delivered energy, as with the well-established European performance-based incentive (PBI) approach. This is generally regarded as the preferred market development method, as it focuses equipment manufacturers, system designers, and system installers on the broader, more appropriate goal of better energy performance and those factors that impact energy. For example,

purchases based strictly on rating tend to place little or no value on proper installation, for example, orienting the array properly, avoiding shading, optimizing the array to the inverter and vice versa, and so forth. The PBI approach is relatively difficult to implement, in large part because energy delivered depends very much on the prevailing weather conditions over which the designer/installer has no control and sometimes little *a priori* knowledge. It can also place the burden on the system purchaser to determine if there is or is not a short-fall (other than weather related), why there is a short-fall, and how to rectify the shortfall.

The second reason for favoring PTC_{ac} is that it takes into account all of the power loss mechanisms (cell conversion efficiency, cell and module mismatch losses, array operating point, various wiring losses, inverter efficiency, etc.). An STC rating does not consider temperature losses at the module level or any other system losses; while a Energy Commission rating applies only an estimated temperature-based module efficiency adjustment and adds to that a best case representative inverter efficiency correction.

Finally, both PTC_{AC} and the Energy Commission use more realistic ambient conditions (PTC_{ac}) representative of clear day spring-through-fall conditions over a large portion of the United States, whereas STC are defined primarily for convenience of testing in a laboratory setting. Throughout this report and this project, PTC_{AC} ratings are the primary standard for parameters that use system rating. However, STC or the Energy Commission rating-based parameters are also reported for comparison.

The ratio of PTC_{ac} to STC (or to the Energy Commission) rating is a good indicator of the "honesty" value of a PV system. The higher the ratio, the closer the match is between advertised and actual performance.

Prior reports in this project (www.pierminigrid.showdata.org/docs.cfm) have discussed in detail the difference between STC and PTC ratings. In the two 12-Month Reports (large systems and small systems) we focused on back-estimating the STC DC rating of each array from our field measurements. This exercise examined how well the as-built system performance compared with factory-based expectations. It was undertaken because of topical PV industry discussions about the two module nameplate ratings (STC and PTC) that lead to unmet expectations. In Europe, purchasers demand that all modules be within ±3% of the rated power, a tight specification that minimizes mismatch as well as ensuring a better actual to advertised power match.

Without such requirements, U.S. consumers are commonly offered a ±10% power output tolerance. In practice, this has evolved to become a 0-10% (no plus sign) tolerance. The consumer might assume that the average power of the modules one purchases is in the middle of the stated ± tolerance, but there is no guarantee of average module rating. The basis of most U.S. incentive programs is on system-rated power.[6] This convention has *discouraged* conservative module ratings—exaggerated module ratings and increased rebates paid by incentive programs. As a result, common module manufacturer "binning" practice has resulted in skewed distributions, with modules above the nameplate rating being labeled as the next higher power-rated product. Lot averages, as a result of this binning practice, tend to be well below nameplate, with 3-5% shy being common. By narrowing the allowable tolerance to ±3%, European consumers are more likely to achieve averages of 1-2% below nameplate. We believe that rather than specifying the tolerance, a better alternative is to require that all modules meet or exceed the rated output. This would exactly reverse the common practice of providing modules that are below or meet the rated output, allow manufacturers to provide any tolerance that is compatible with their production capabilities, and provide consumers with better information for predicting the economic return on their PV system investment.

The second issue, initial light-induced degradation (LID), is a factor that has long been accounted for in ratings for thin film modules. It is now widely acknowledged that crystalline modules are subject to LID of 2-3%, which occurs in the first few hours of exposure. Unlike amorphous silicon and other thin films, LID is not commonly accounted for in the nameplate rating. As a result of these two factors alone, it is not unreasonable to expect a PV array to be 5-10% below nameplate, even after properly accounting for mismatch, wiring, and other losses.

3.3.2 System Performance

3.3.2.1 Sample Initial Characterization

As an example, in this final report we use excerpts from the original 52-page *Characterization Report for the PowerLight Sloped PowerGuard PV* power system.

Characterization reports were designed to provide an overview of the documentation, design review, installation review, and initial performance of the various systems. The information and results are intended for a sophisticated reader, one with at least some

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[6] In Germany and other European communities, the incentives are instead based on energy production.

basic knowledge of solar energy and PV. Full Characterization Reports have many details including the following sections: System Description, Test Facility, Procurement and Review Process, Documentation Review, Contents of the System Documentation, Evaluation of the System Documentation, Documentation Strong Points, Documentation Weak Points, Installation Review, Shipping, Array Installation, Electrical Balance of Systems (BOS) Installation, PV System Initial Performance Review, Module Characterization, Inverter Characterization, Efficiency, MPPT Effectiveness and Tare Loss, Reliability Estimate, Array Mounting Effects on Performance, Field Wet Resistance Test, Results, Initial System Performance, Rating Conditions, System AC Rating, System Start-Up Difficulties, Array Area Requirements, Energy Production, Monitoring, Data Acquisition & Outreach, Review of Costs, Availability of Cost-Share and Rebate Funds, Cost Summary, and a Sandia Inverter Performance Report.

Rated at a nominal 20 kW, the system (see Figure 8) is small compared to other PowerLight PowerGuard PV system installations but is fully representative, incorporating all components and critical aspects of their larger systems. PowerLight offers the Sloped PowerGuard system in standard sizes ranging from 10 kW to 225 kW. Major components of the Sloped PowerGuard system include 120 of Sanyo's HIP-190BA2 high-efficiency photovoltaic modules, on PowerLight's tilted mounting system, connected to a Xantrex PV-20208 three-phase inverter. The inverter had not been independently characterized. BEW worked with Sandia to develop appropriate test procedures and to perform a subset of those procedures on the inverters used at the IEUA facility.

Figure 8 **PowerLight Sloped PowerGuard 20kW PV System.**

3.3.2.1.1 System Description

This 20-kW Sloped PowerGuard system uses 120 of the Sanyo HIT Model HIP-190BA2 high-efficiency photovoltaic modules. Measuring 52" x 35.25" (1.32 m x 0.90 m). The manufacturer specifications for the module are shown in **Table 5**:

Table 5 Manufacturer Specifications for HIP-190BA2

Description	Notation	Value
Power (max.)	Pp (watts)	190 W
Voltage at maximum-power point	Vp (volts)	54.8 V
Current at maximum-power point	Ip (amps)	3.47 A
Open circuit voltage	Voc (volts)	67.5 V
Short circuit current	Isc (amps)	3.75 A
Nominal operating cell temperature	NOCT (Celsius)	44.2 °C
Power temperature coefficient	T_K (Pp)	-0.30 %/°C
Open circuit voltage temperature coefficient	T_K (V_{oc})	-0.169 V/°C (-.25%/°C)
Short circuit current temperature coefficient	T_K (I_{sc})	N/A
Series cells per cell string	Nseries	96
Parallel cell strings per module	Nparallel	1
Maximum System Voltage	Vsys,max	600 V
Operating temperature, minimum	Tambient,min	-20 °C
Operating temperature, maximum	Tambient,max	+40 °C
Connection type	Two 12AWG single conductor USE-2 terminated with Multi-Contact connectors	

Note: Sanyo graded HIT modules into three nominal power ranges (175 W, 190 W, and 205 W), the modules reviewed in this system are the 190W grade.

The array is arranged in 15 series strings of 8 modules with a footprint of approximately 33′ x 74′ or 2,440 square feet. A single Xantrex PV-20208 inverter processes the power and connects to the building 480 V_{AC} power through a step-up 208/480 V isolation transformer. The inverter is located in a dedicated, conditioned room within the building.

The array’s 10-degree tilt is less than the 30-degrees needed for maximum annual energy at the Chino, California, location.

At its factory in Berkeley, California, PowerLight mounts each solar power module on an extruded polystyrene foam insulating “tile” (see **Figure 9**).

Figure 9 A PowerGuard tile and installation.

The Sloped PowerGuard system is installed at the IEUA headquarters building in Chico, California, which hosts the evaluation of several similarly sized PV systems (see **Figure 5**).

Lifting to the roof was accomplished with a truck-mounted crane owned and operated by the IEUA (see **Figure 10**).

Figure 10 Shipping container being lifted by truck crane

There was no breakage caused by the shipping, handling, or lifting of the equipment. The extra blue board was laid under each pallet to spread the load of the pallet evenly on the roof and to prevent protrusions from damaging the roof membrane.

Personnel with no previous experience with the PowerLight system assisted in the array installation. PowerLight provided oversight and guidance for the installation with two PowerLight personnel who guided additional two to four workers throughout the installation. The array installation took place over a two-day period. On the first day, the array location was finalized, the panels installed, and the array assembled.

To keep clear of all shading obstructions (in particular the HVAC screen in Figure 5) and large obstacles (for example, skylights), the center of the roof was chosen for the array. This location was ideal with the exception of a single plumbing vent that could not be relocated. This vent was used as the key location around which the rest of the array was located. **Figure 11** shows how the vent fit neatly behind a panel in the second row of modules. The entire layout process and setting of all 120 panels took about half a day.

Figure 11 Array layout placing vent between module and wind shroud.

By the end of the first day, most of the wiring within the array was complete and the entire array grounding installed (see **Figure 12**, **Figure 13**, and **Figure 14**). On the second day, the array wiring was completed and several miscellaneous projects were accomplished such as placing signs, running the array wires to the rooftop junction box, and final cleanup.

Table 6 Installation Labor Summary

Day	# of workers	Total Labor Hours	Activity
1	6	48	Roof Prep, install array and most wiring
2	4	20	Complete circuit wiring to junction box, finish misc. items
TOTAL		68	

A total of 68 labor hours was used to install the entire 20-kW array as summarized in **Table 5**. It should be noted that this was only the third installation of this particular product; four of the six workers had not worked on this system previously. Southern California Roofing, the company that installed the membrane roof, provided most of the installation labor. A trained, experienced crew could probably complete the array installation in 50 labor-hours.

Figure 12 Installing grounding straps after all panels were placed on roof.

Figure 13 Installing perimeter ballasted curb w/concrete pavers.

Figure 14 Lifting module-shroud assembly and snapping shroud into slots (home run wire for series strings already in place).

3.3.2.1.2 Electrical Balance of Systems (BOS) Installation

The electrical balance of system installation consisted of running 10 AWG wire from the rooftop junction box to the combiner box that was located on the roof. Since the array has 15 independent series strings, 15 pairs of wires were run to the combiner box where each circuit was terminated on a fuse block and combined into a single array circuit. This array circuit was connected to a rooftop disconnect (added by the project to facilitate testing—see **Figure 15**) before running through conduit to the PV room set aside within the IEUA headquarters building. The DC disconnect, inverter, isolation transformer, and AC disconnect were installed in the PV room. Standard utility pulse-initiating kWh meters were installed to monitor system output power and energy.

Figure 15 Disconnects for all 12 rooftop systems.

Power was routed from the PV room to the building's main electrical room about 20 feet away and fed through a dedicated circuit breaker to a 480 V AC service panel. A 12-kV transformer at the adjacent building 100 yards away energized this panel.

The electrical maintenance personnel of the Inland Empire Utilities Agency (IEUA) provided the labor for the electrical balance of system installation. All the wiring from the rooftop array through the inverter room to the service panel inside the building was run by IEUA. It took a total of approximately 60 labor hours to install all the electrical related to this system. It is difficult to develop an exact number for this project since all three 20 kW segments were under construction at the same time. Much of the labor was shared among the various installations.

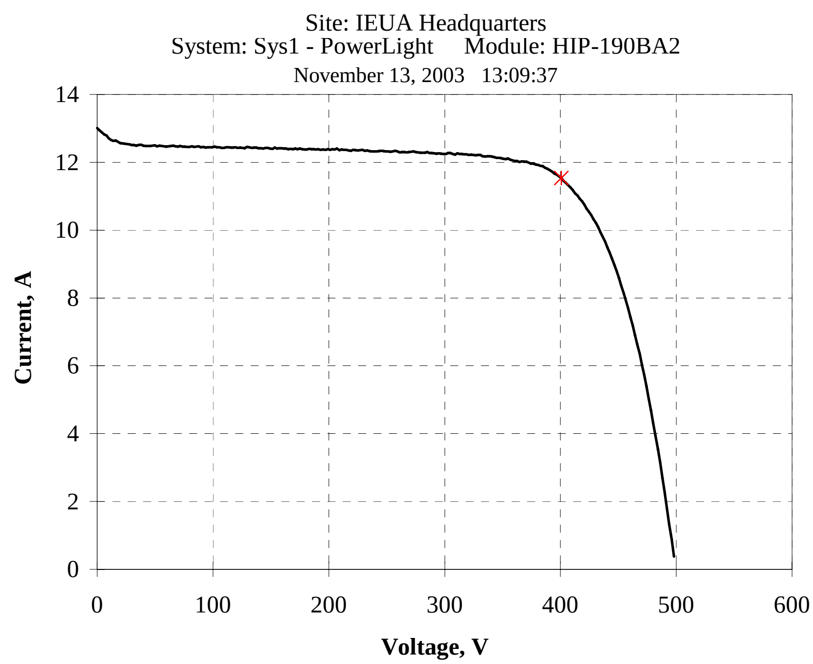
Figure 16 Final Inverter Installation.

3.3.2.1.3 PV System Initial Performance Review

3.3.2.1.3.1 Initial System Performance

3.3.2.1.3.1.1 Rating Conditions

Figure 17 shows a representative system I-V curve, this one taken at an irradiance of 651 W/m^2 with the array operating at 42^o C and an ambient temperature of 17^o C. Under these conditions, the maximum DC power was 4,671 watts at 395 V_{dc} and 11.8 A_{DC}. At a PTC irradiance of 1000 W/m^2 and at 20^o C ambient temperature the array is expected to rise about 6^o C above the temperature measured during the IV curve test. The power loss due to temperature defined by Sandia is –0.32%/^{o}C, so the temperature impact will reduce the irradiance-adjusted value by about 2% (6^{o}C x (–0.32%/^{o}C) = -1.92%). The simple method for estimating the performance at a different irradiance than measured is to take the ratio of the measured irradiance to desired irradiance and multiply that value by the original performance (for the above example, 1,000 (w/m^2) /651 (w/m^2) x 4,671 (w) x 0.98(temp) = 7,032 watts).



Voc:	498 V	Vpp:	401 V
Isc:	13.0 A	Ipp:	11.5 A
FF:	71.3 %	Ppp:	4,623 W
Direct Normal Irrad. :	640 W/m^2	Global POA Irrad. :	0 W/m^2
Tmod:	41.0 °C	Tamb:	0.0 °C

File: PWRL0105

Figure 17 IV Curve for 1st Third of PowerLight Array.

The sum of three IV curves for the three array strings makes up the overall DC performance of the system at 21,107 watts. Adjusting this value by 6% for inverter efficiency yielded a preliminary rating of 19.8 kW_{AC} PTC (21,107 watts x 0.94 (inverter efficiency) = 19,841 kW). Because this data was collected in January and the array tilt was shallow, measured conditions were quite different than PTC conditions. We estimated that it was possible that this value was in error by as much as 15% due to errors caused by incidence angle, measurements, and translation of values to PTC. As it turned out, the rating based on system operating data was 18.0 kW, or 9.3% lower than our original estimate.

Using the Energy Commission/CPUC method for determining system size, this PowerLight Sloped PowerGuard system is considered a 20.6 kW system (178.7 W/module x 120 modules x 0.96 inverter efficiency = 20,586 watts), a value that is 4% greater than the rating estimated using the initial IV curve data, and 15% higher than the rating based on system operating data.

3.3.2.1.3.2 System Start-Up Difficulties

During initial testing, it was discovered that the inverter maximum power point tracking function (MPPT) was having difficulty with the Sanyo array. After numerous tests and evaluation of the problem with responsive support from both PowerLight and Xantrex, an interim solution was developed that solved most the tracking problems observed. A final solution was implemented in May 2004. Other than this array-inverter interrelation issue, the PowerLight Sloped PowerGuard system has met the general expectations of a commercial product in a mature market.

3.3.2.1.4 Review of Costs

3.3.2.1.4.1 Availability of cost-share and rebate funds

Initially established through the state's electric utility restructuring plan, both the California Energy Commission and the California Public Utilities Commission manage rebate programs to offset the capital cost and encourage the use of PV equipment. The CPUC Self-Generation incentive Program offered \$4,500/kW_{ptc} for PV and other systems between 30 kW to 1 MW, with a cap of 50 percent of the installed cost. The PowerLight system was installed simultaneously with 11 other systems totaling a rebate system size of 60 kW and was therefore eligible for the CPUC Self-Generation Incentive Program.

3.3.2.1.4.2 Cost Summary

The following table provides a breakdown of the costs for the 20 kW PV system. These costs come from the actual expenditures on the project. Some of the costs for site engineering and maintenance were estimated by the percentage of time and effort relative to the overall project since several of the activities were parallel for all 60 kW of the project.

Table 7 Cost Summary of 20 kW PV System.

Item	Costs
System Hardware and PowerLight Engineering	$150,000
Shipping	$2,400
Site Engineering and Installation	$13,000
Total Costs	$165,400
CPUC Self-Gen Incentive	$82,700
Funding Provided by Commerce Energy	$82,700

3.3.2.2 Large Systems 12-Month Performance Summary

The large system evaluation covered the selection, installation, operation, monitoring, and evaluation of three independent 20-kW PV systems installed on the roof of the IEUA Headquarters building in Chino, California. The preceding section discussed the installation of one of these 20-kW systems as an example of system initial characterization, while this section will discuss the retrospective analysis of the performance of all three 20-kW systems.

Figure 18 shows that Chino is located approximately 50 miles east of Los Angeles in the San Bernardino Valley.

Figure 18 Regional map showing location of Chino, California.

The average annual air temperature in Chino is about 16 °C (61 °F), with typical range of -2 to 40 °C (29-103 °F). Average wind speed is 1.5 m/s (3.4 mph), with a sustained peak of 6.7 m/s (15 mph)[7]. Annual average daily peak hours of sunlight on a horizontal surface is 5.4 hrs, with monthly average range about 2.7 hrs in December to 7.6 hrs in June.[8] The Chino area has an extensive dairy and other livestock industry producing more airborne soil contaminants than most urban and suburban sites. This airborne soil collects on PV modules and reduces photovoltaic output.

These systems were intended to be indicative of the kinds of Building Integrated PV hardware that were common to commercial installations in California. While these sample systems may not all represent actual building integrated products (or, those designed to replace traditional building roofing, glazing, or cladding materials), they were representative of then-currently available electrical technologies (PV cells/modules, structures, inverters, wiring, and so forth.) that have been or could be used to make BIPV products.

Installation of these systems was completed in October 2003, and final approval to interconnect was received February 26, 2004. Thus, the starting date for operation was taken to be March 1, 2004, and the period of performance covered in this report is from that date through February 28, 2005, with some use of additional data acquired through April 2005. Table 8 summarizes the systems evaluated in this project. As the table shows, for our large systems category there are 6 different mounting systems, 9 module manufacturers, 12 different modules, and 9 different PV module technologies.

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7 Basic weather data derived from four years of Pomona weather data commencing in January 2000, obtained from http://www.cimis.water.ca.gov.

8 Solar resource data provided by the NASA (National Atmospheric and Space Administration). Surface meteorology data site on the web at http://eosweb.larc.nasa.gov/sse/ .

Table 8 Large System Descriptions

Site	Integrator	Module	Tech	Inverter	Mount	Ratings			
						PTC kW	CEC kW	STC kW	PTC/ STC
IEUA, Chino, CA	PowerLight	Sanyo HIP-190BA2	HIT	Xantrex PV20-208	Sloped PG	17.97	20.59	22.80	0.81
	Schott Solar	Schott 300-DGF/50	EFG		SunRf FS	18.52	20.67	24.00	0.77
	IES	UniSolar US-116	a-Si	SMA SWR 2500U	Quilt	1.86	2.07	2.32	0.80
	SIT	UniSolar PVL-128	a-Si		SIT	1.89	2.05	2.30	0.82
	N/A	Shell Solar ST40	CIS		Custom	2.13	1.99	2.40	0.89
	First Solar	First Solar FS-45	CdTe		EZ Mount	2.10	2.17	2.43	0.86
	IES	AstroPower APx-130	pc-Film		Quilt	1.63	2.11	2.73	0.60
	N/A	Evergreen EC-102	SR-pc		Custom	1.90	2.06	2.45	0.78
	N/A	BP Solar SX-140	pc-Si		Custom	1.95	2.09	2.52	0.81
	N/A	Schott SAPC-123	pc-Si		Custom	1.94	2.03	2.46	0.79
	N/A	Shell Solar SP140	mc-Si		Custom	2.02	2.13	2.52	0.80
	N/A	AstroPower AP-110	mc-Si		Custom	1.95	2.09	2.40	0.81
	TOTAL					55.7	62.2	71.6	0.78

Technology:
HIT: Mono-Crystalline Silicon surrounded by thin Amorphous Silicon layer
EFG: Edge-defined Film-fed Growth Poly-Crystalline Silicon
a-Si: Triple-Junction Amorphous Silicon
CIS: Copper Indium Diselenide
CdTe: Cadmium Sulfide/Cadmium Telluride
pc-Film: Poly-Crystalline Silicon Film
SR-pc: String Ribbon Poly-Crystalline Silicon
pc-Si: Poly-Crystalline Silicon
mc-Si: Mono-Crystalline Silicon

There are two primary reasons for the higher PTC to STC ratios shown in Figure 19. The first factor is that the temperature coefficient, which accounts for the loss of power due to rise in module temperature, is roughly half that of standard crystalline silicon products. This lower temperature dependence means that the higher temperature under PTC will have less of an effect on the power output, keeping it closer to its STC rating. For crystalline silicon PV modules, there is an 8-13% reduction in output power between STC and PTC conditions. For amorphous silicon (US-116 and PVL-128) and CdTe (FS-45), the reduction is 4% - 7%. This factor will be especially evident in the difference between STC and the Energy Commission ratings, since the latter is a temperature-corrected version of the former (and includes an estimate of inverter efficiency, which is a common value to the 10 segments of the multi-inverter system).

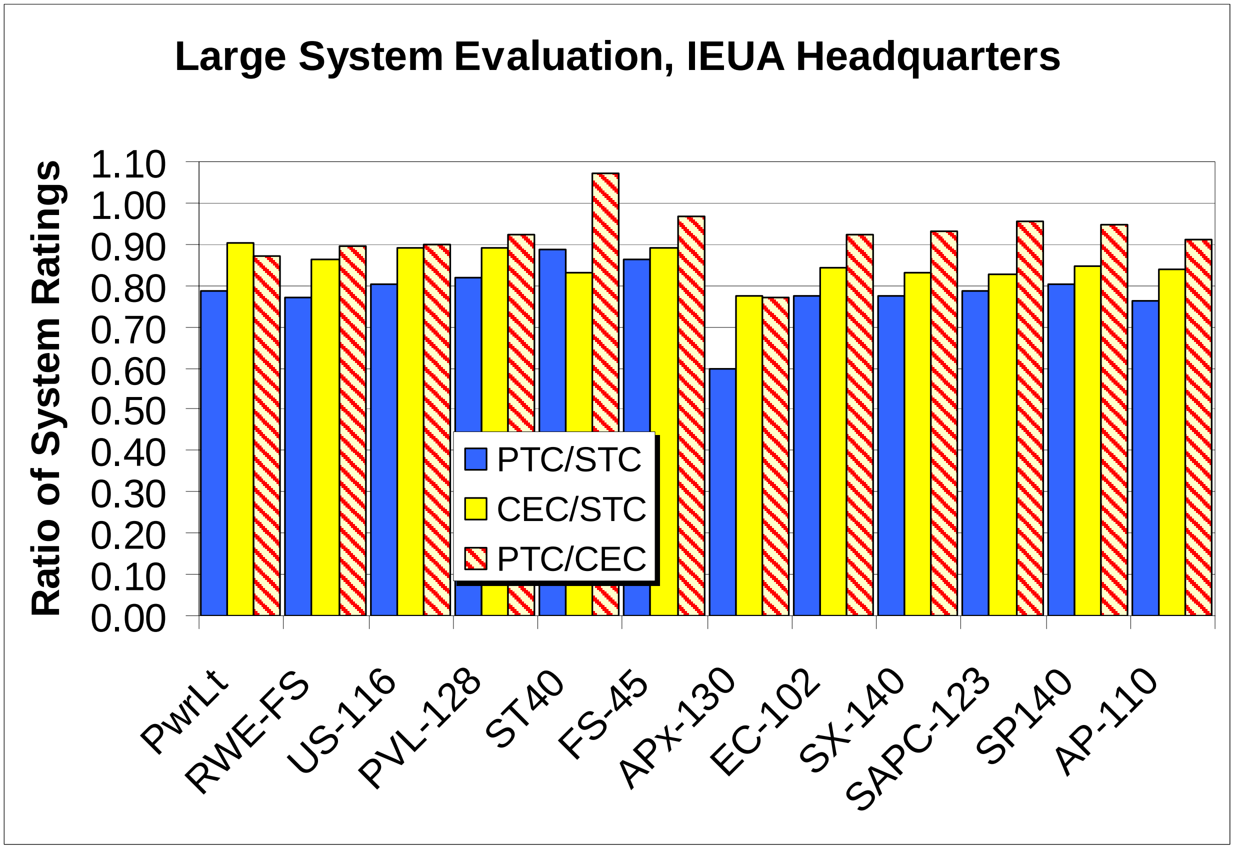

Figure 19 Large Systems Comparison of PTC, the Energy Commission, and STC System Ratings

In the case of the UniSolar US-116 and PVL-128, a second factor is that amorphous silicon modules are subject to much higher initial degradation than crystalline modules. While crystalline silicon modules will experience a 1% to 3% drop in output power in the first few hours of exposure to sunlight with no significant drop in the following months, amorphous modules will degrade 10% to 20% over the first 6 to 12 months of exposure. To ensure that fielded modules meet their ratings over their lifetimes, manufacturers of thin film products must provide STC ratings that represent performance following the initial degradation. As a result, early in the life of the system, thin film modules tend to perform better than their ratings. Conservative ratings are not the norm in the PV industry and usually indicate that the manufacturer is anticipating this initial degradation.

Looking at the PTC/the Energy Commission ratios, the ST-40 PTC rating actually exceeds the Energy Commission rating, again, likely due to a conservative prediction of initial degradation by the manufacturer. Other than the APx130 system, the Energy Commission ratings are all within 15% of the actual system rating, many at or above the 90% level. The APx130 system is a crystalline silicon film product that has slightly higher temperature dependence than standard crystalline silicon and is, in this mounting configuration, exposed to much higher operating temperatures than the other crystalline products. Because of the high temperature dependence of crystalline silicon film, it has the lowest ratio of the Energy Commission/STC rating. Given the high operating temperatures of the Solar Quilt installation, it was expected that the APx-130 system would have the lowest PTC/STC and PTC/the Energy Commission ratios. However, in this case the temperature was so high at the rating conditions that it caused the maximum power voltage of the array to fall below the minimum DC voltage of the inverter, limiting the power output at PTC conditions, thus lowering both the PTC rating and the PTC/the Energy Commission and PTC/STC ratios even more.

Figure 20 and Figure 21 show the initial and final PTC ratings after one year of operation. Ideally such rating estimates would be recomputed periodically over several years to identify degradation rates, but the duration of this project only allows for a one-year re-evaluation. The most obvious feature is the apparent improvement in ratings after one year of operation for seven of the systems, but the confidence intervals overlap in all but one instance. Therefore, we cannot conclude that this is a significant statistical variation. The SP-140 rating jump does appear to be statistically significant and is probably due to soiling that was not observed during the initial rating period for that subsystem (5/30/2004 through 6/1/2004). The higher of these two ratings has been used as the PTC rating throughout this report.

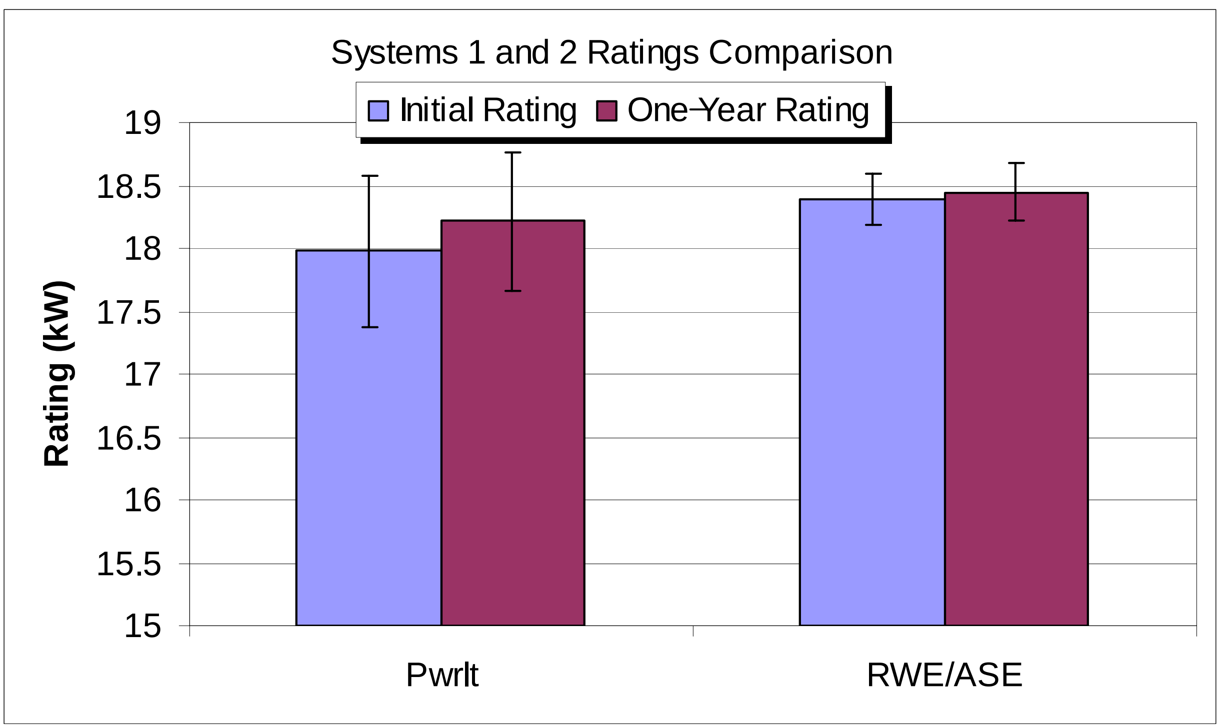

Figure 20 Systems 1 and 2 Ratings Comparison

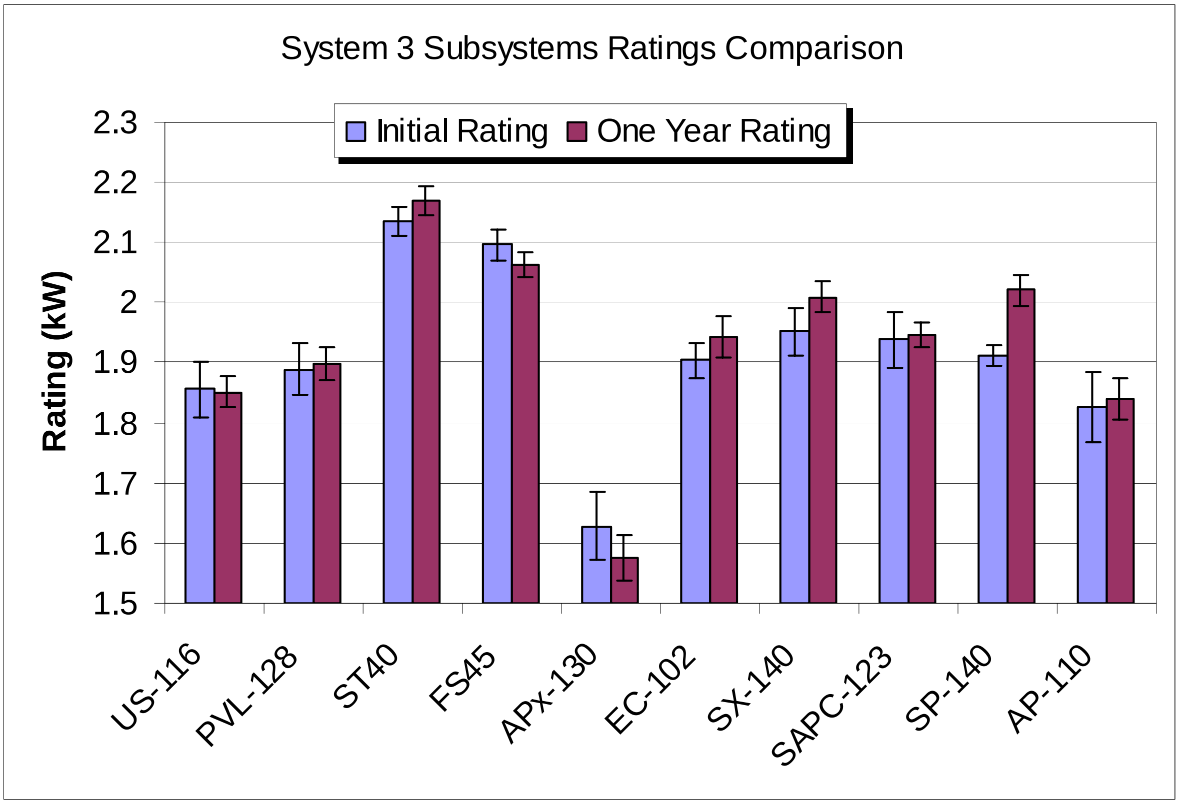

Figure 21 System 3 Subsystem Ratings Comparison

Figure 22 shows a normal probability distribution based on the measurement uncertainties in our data acquisition system. The most likely array power output at STC conditions based on measurements would be at the peak probability value, or 20.8 kW labeled "Best Est." in the plot. "Nameplate" is the expected array STC output (sum of STC module ratings less 4%) of 21.2 kW; the "Max" and "Min" values are 10% above and below nameplate (also reduced by 4%) or 24.1kW and 19.7kW, respectively. While it can be said that the difference between the best estimate and nameplate is "within the measurement uncertainty," it's more accurate to say that there is a roughly 3% chance the actual rating is greater than nameplate and a 97% (93%+4%) chance the actual rating is less than nameplate. In fact, there is almost a 4% chance that the actual rating is below the manufacturer's guaranteed minimum output (and, for completeness, 0.000001% probability that the actual rating exceeds the +10% maximum rating).

Figure 23 summarizes the analyses just described for all 12 large systems. It indicates that, after allowing for 4% of combined losses, just one of 12 systems was likely to have met its nameplate rating. A third showed a 49% likelihood, and all others were far lower. With the yardstick set an additional 10% lower to correspond to manufacturers' minimum binning specifications, the translated field ratings suggest that all but one of the 12 systems met the more forgiving criteria. The SIT/Astropower APx-130 system's field rating came in 20% below the nominal sum-of-all-modules nameplate, but an indeterminately large element of this shortfall came from having the array voltage depressed below the inverter maximum power tracking range by high temperatures. Therefore, this result should not be used to draw conclusions regarding the APx-130 module rating.

Revisiting Figure 22, this analysis suggests that it is common for consumers to receive PV modules that are on the lower end of published specifications. Although these data are limited, field experience over the past few decades supports this conclusion. This situation is further complicated in a world market where module rating requirements differ. Both Germany and Japan have significantly more strict tolerance allowances on modules than does California. This lack of a strict tolerance in California is almost certain to have the undesirable effect of leaving the California program with those modules that do not meet the grade for Japan or Germany. In other words, if Germany requires modules to be within 3% of nameplate rating and California requires 10%, then California is more likely to receive modules that are between 3% and 10% below rating. The statistics presented in Figures 5 and 6 seem to support that deduction. A proposed solution to this situation is presented in Section 4.3.1.

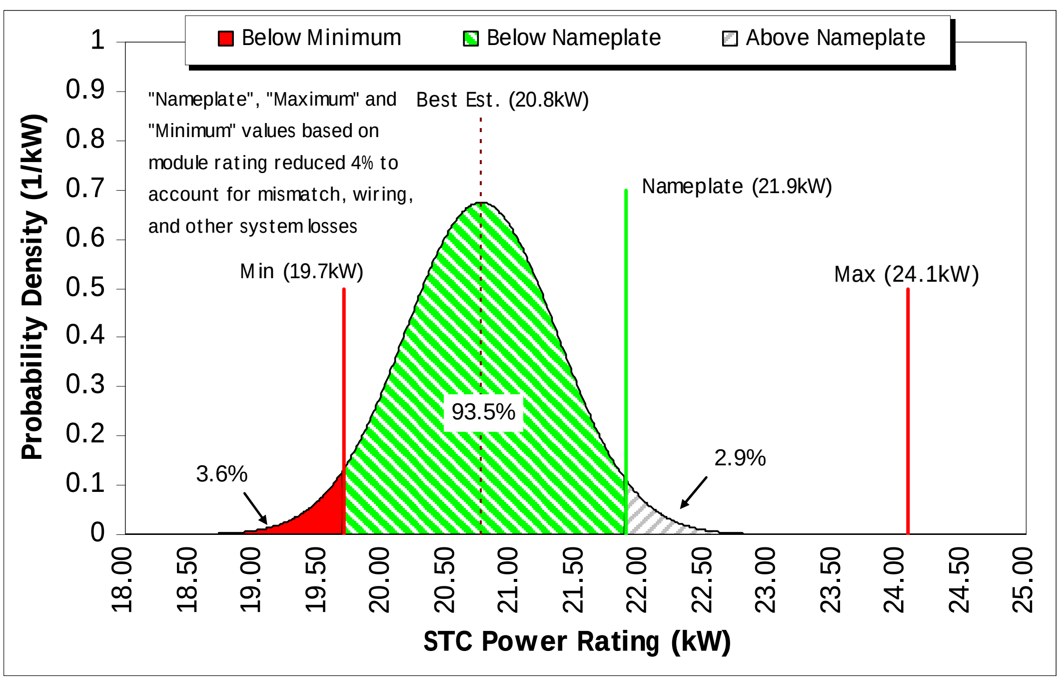

Figure 22 PowerLight STC Array Rating Extrapolated from Field Measurements.

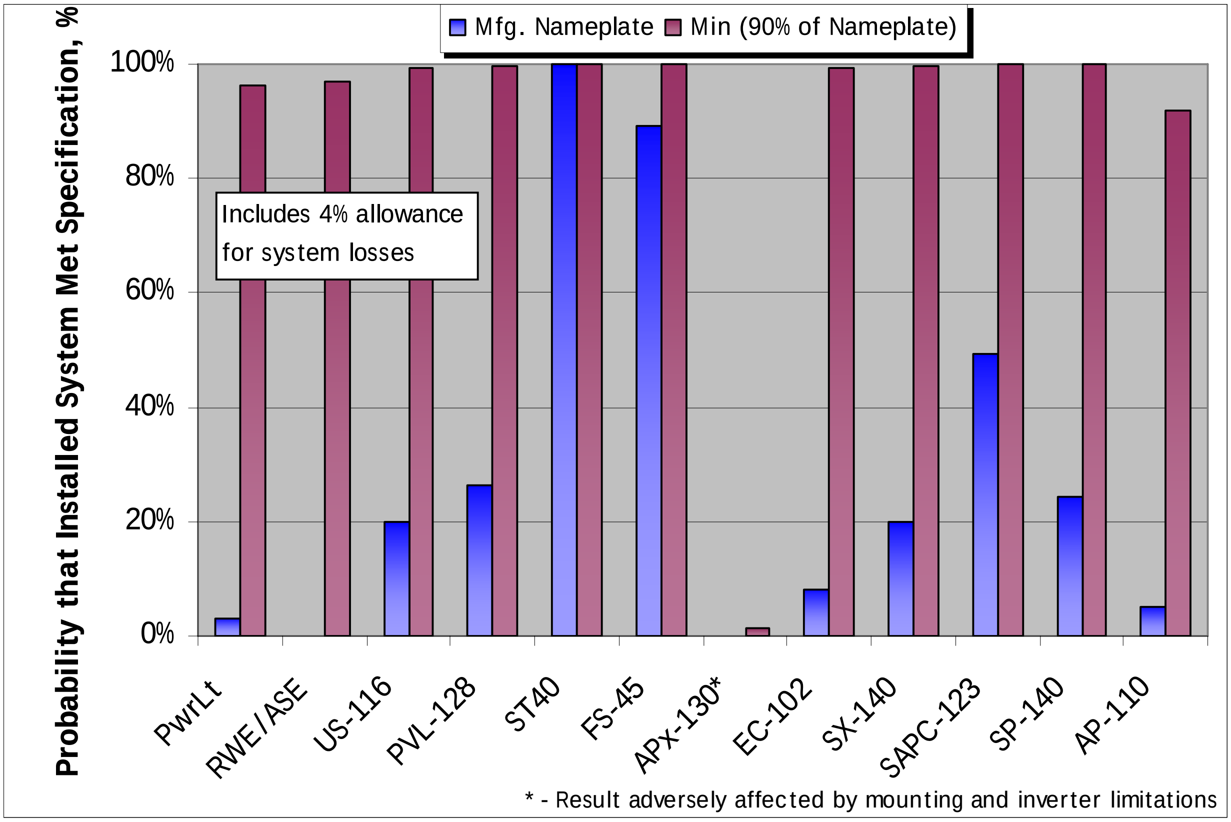

Figure 23. Probability that field -based STC dc ratings agree with two factory-based thresholds.

3.3.2.3 Small Systems 12-Month Performance Summary

The small system evaluation covered the selection, installation, operation, monitoring, and evaluation of three independent 2-kW PV systems installed on a mock roof at the Photovoltaics for Utility System Applications (PVUSA) facility in Davis, California, as shown in Figure 24, Figure 25, and Figure 26. This facility, currently managed by Renewable Ventures, has a long history of testing and evaluating PV systems from 2 kW to 400 kW in size. These three test systems were intended to be indicative of the kinds of residential-class building integrated PV hardware that are currently installed under the Energy Commission's Emerging Renewable Rebate Program as well as those to be installed under the Governor's Million Solar Roofs Program. These systems represent currently available electrical technologies (PV cells/modules, structures, inverters, wiring, and so forth) that are used by the thousands in the California market. As of 2005, some 15,000 residential systems were installed and operating in the state of California.

Figure 24 Sharp Array

Figure 25 Kyocera Array

Figure 26 Schott Solar Array

Installation of these test systems was completed and the systems energized in May 2004. The starting date for operation was taken to be June 1, 2004, and the period of performance covered in this report is from that date through May 30, 2005. **Table 9** summarizes the evaluated small systems. The Sharp and RWE Schott systems both employ Sharp polycrystalline silicon modules in arrays of nearly identical size with two inverters conditioning the array power: the Sharp JH-3500U inverter in the Sharp system, and the SMA SB2500U inverter on the RWE Schott system. The other system under test is provided by Kyocera using Kyocera polycrystalline silicon modules with an SMA SB2500U inverter. All three systems were packaged with UniRac SolarMount mounting systems.

Table 9 Summary of Systems in Small PV System Comparison

System	Module		Inverter		Tech	Mount	Area m^2	P_{CEC} kW	P_{STC} kW
	Mfr.	Model	Mfr.	Model					
1	Sharp	ND-123U1	Sharp	JH-3500U	pc-Si	SolarMount	33.8	2.38	2.95
2	Kyocera	KC167G	SMA	SWR-2500U	pc-Si	SolarMount	30.2	2.11	2.51
3	RWE/Schott	SAPC-165	SMA	SWR-2500U	pc-Si	SolarMount	29.2	2.45	2.97
Total							93.2	6.9	8.4

As Table 10 for small systems clearly shows, all three have very similar ratings. **Figure 27** illustrates that the ratio of PTC/STC rating is about 0.8, which is consistent with previous experience for well-designed and properly performing systems. PTC ratings were about 5% lower than the Energy Commission rating illustrating the point that the Energy Commission rating misses several smaller losses captured in the PTC rating. The ratio of the Energy Commission/STC rating is approximately 0.83 which is consistent with the two primary adjustments made in the Energy Commission rating: 1) approximately 0.88 for the adjustment of module rating from STC to the Energy Commission conditions; and, 2) approximately 0.94 for inverter efficiency (taken together 0.88 x 0.94 = 0.83).

Figure 28 shows the initial and final PTC ratings after one year of operation. The most obvious feature is the apparent decline in ratings after one year of operation, but the confidence intervals overlap enough that we cannot yet conclude that this is anything more than expected statistical variation. Typical crystalline silicon module degradation rates are 1%-2%/year

Table 10 Summary of System Efficiencies and Ratings

Array	Manufacturer	Model	Tech	Mount	Area	EffSYS	RatingPTC	RatingCEC	RatingSTC	PTC/STC
					sq. m.	%	kW	kW	kW	rating ratio
Sharp	Sharp	ND-123U1	pc-Si	SolarMount	33.8	6.80	2.3	2.4	3.0	0.78
Kyocera	Kyocera	KC167G	pc-Si	SolarMount	30.2	6.66	2.0	2.1	2.5	0.80
RWE/Schott	RWE/Schott	SAPC-165	pc-Si	SolarMount	29.2	8.22	2.4	2.5	3.0	0.81
TOT					93.2	7.20	6.7	6.9	8.4	0.80

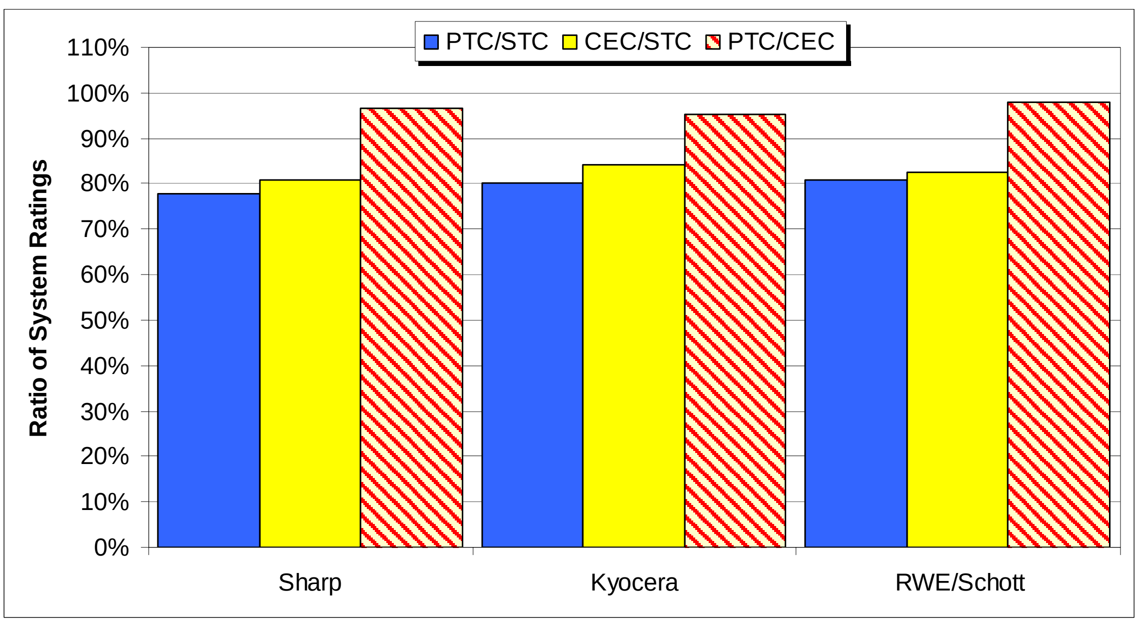

Figure 27 Small Systems Comparison of PTC, the Energy Commission, and STC System Ratings.

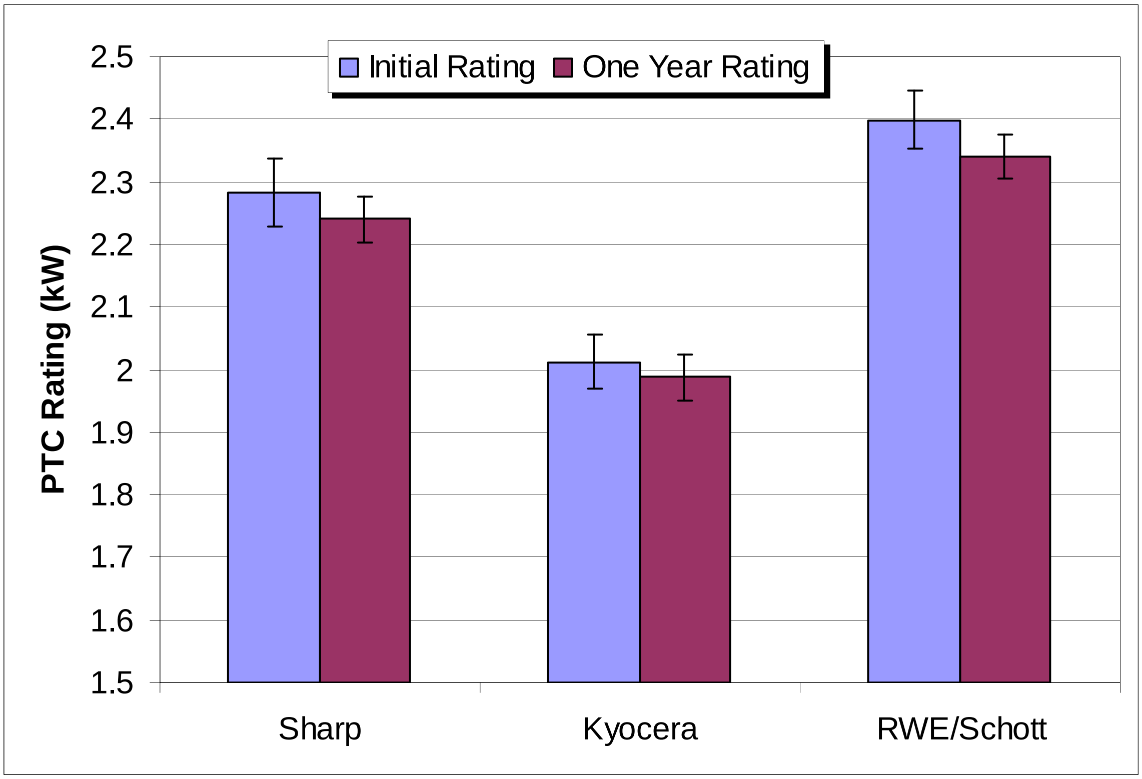

Figure 28 Initial and One-Year PTC Ratings Comparison.

Figure 29 shows results of rating analyses performed using the technique shown in Figure 22. The field-based rating will always be a few percentage short of the nominal nameplate rating simply due to the unavoidable effects of mismatch, wiring, inverter maximum power point tracking accuracy, LID, dust and shading losses. As before, we allowed 4% for these effects. This figure indicates that, after allowing for the 4% combined losses, only one of three systems was likely to have met its nameplate rating. With the yardstick set an additional 10% lower to correspond to manufacturers' minimum binning specifications, the translated field ratings indicate that all of the systems met (had a better than 50% chance of exceeding) the more forgiving criteria.

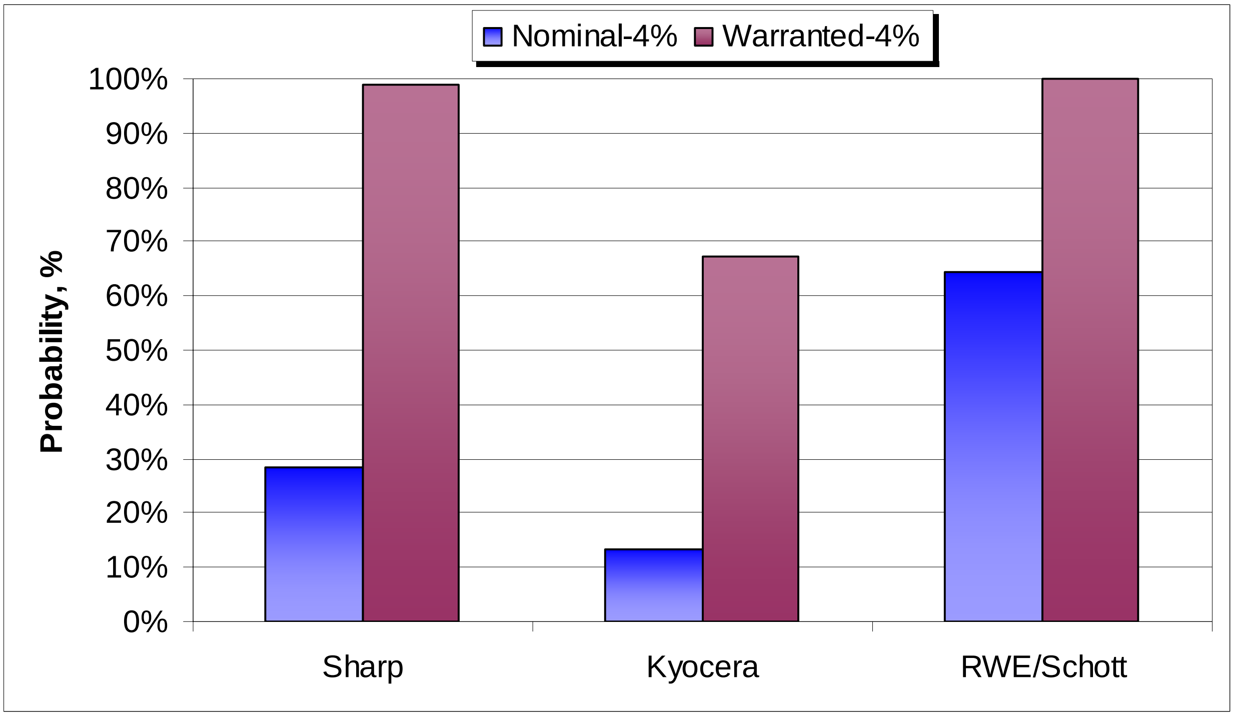

Figure 29. Probability that field -based STC dc ratings agree with two factory-based thresholds

3.3.3 Reliability

Twelve months of operation is too short to expect to find anything but infant mortality problems, especially since the majority of the equipment under test had been fielded in substantial numbers. Therefore, reliability was not a major focus of this evaluation.

3.3.4 Technology Transfer

The project produced 10 major reports (four initial characterization, two 6-month performance, two 12-month performance, and two Consumer Confidence Guidelines), three conference presentations, several project and RPAC presentations, created a substantial Web presence, and provided targeted workshops. The project reports have been covered in detail in the previous sections. Here we will focus on the Web page and workshops.

3.3.4.1 Web Presentation

The BIPV Testing and Evaluation Project website was hugely successful at describing the systems under test, presenting the real-time performance information, and generally documenting project results. **Figure 30** shows snapshots of the BIPV Testing and Evaluation Project website, including (clockwise from upper right): welcome page with links to the Commerce Energy PIER Mini Grid website and participant logos; graph of one week of irradiance input and power output; documents page with links to completed reports; and system descriptions with key descriptive parameters. Graphs were automatically updated four times per hour, and notes on system operation were added manually as information about operational events was communicated to project personnel.

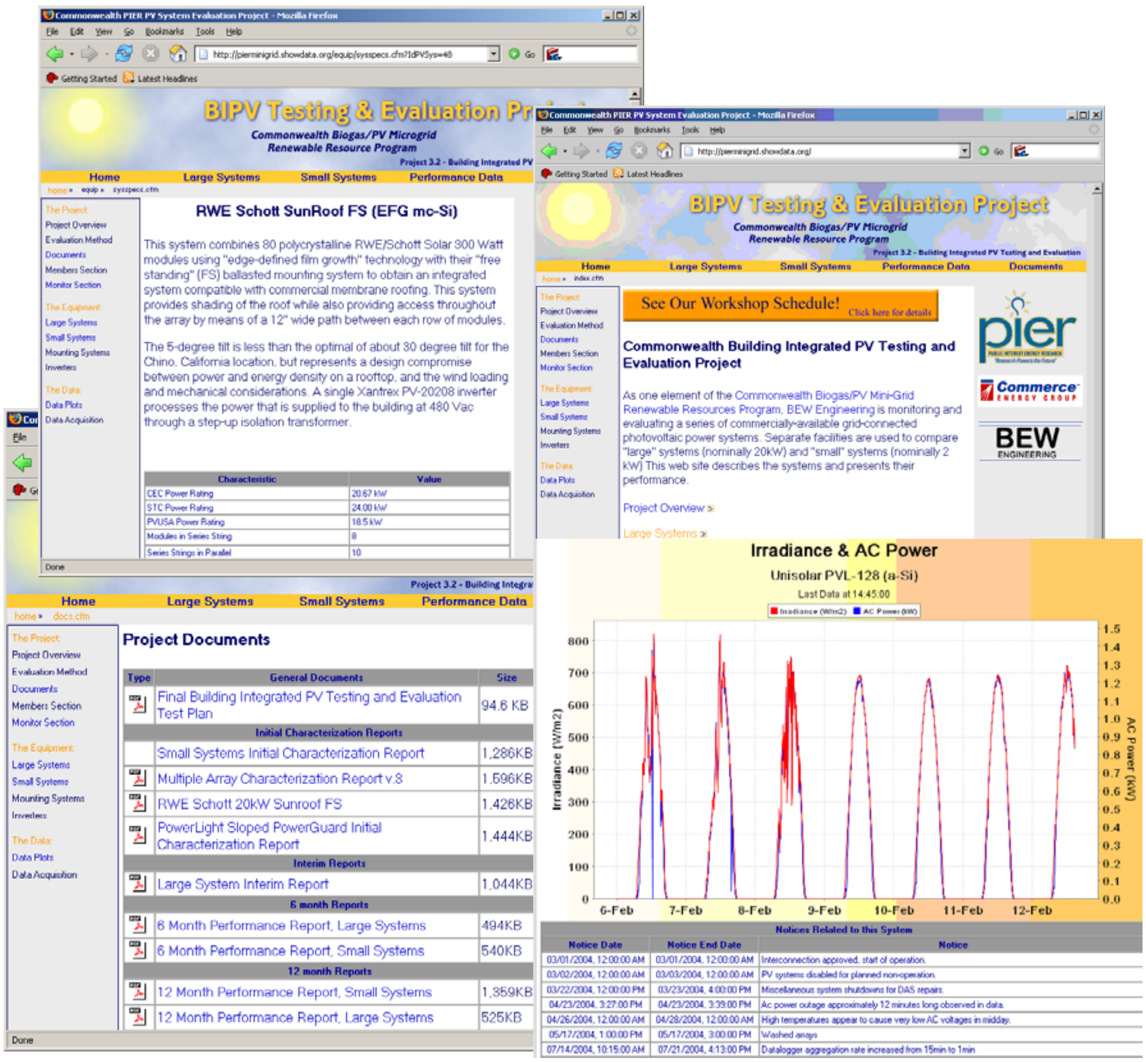

Figure 30. Sample Web Page Snapshots

Website activity included visits from almost 4,500 distinct users downloading 400 copies of the available documents.

3.3.4.2 Training (Workshops)

Once the cost of the three-day workshop was reduced from almost $300 to $75 per person for early registration, the number of registrants dramatically increased for the second and third workshops. These workshops were held in Sacramento and Chino, respectively. Key outcomes include the fact that 170 motivated and interested workshop participants were exposed to the PIER results. Key findings from the project were discussed in detail during the workshop sessions, and many participants were able to see the project testing facilities firsthand. Tours were conducted at the PVUSA site for the Sacramento workshop attendees and at the IEUA site for the Chino attendees. Since neither of these facilities is open to the public for tours, this provided an important opportunity to display various aspects of the project.

4. Conclusions and Recommendations

By any objective measure, the project met or exceeded its initial goals and objectives. California PV consumers and those across the country have had, for nearly two years, an unprecedented open window on the actual performance of 15 PV systems representative of the styles and equipment they are likely to buy. Some 4,500 Web visitors have been able to learn about the systems under test, view real-time performance data, and find detailed analysis performed by local experts and reviewed by noted experts from around the country.

The few minor issues encountered over this initial phase[9] of the project—most of which can be related to the more developmental nature of some of the products selected—do not detract from the basic conclusion that PV systems designed and installed properly, and rated appropriately, perform as expected. The PV industry is providing California consumers with a wide range of excellent products, and it can be a daunting task to figure out which product best suits a particular consumer's needs. The BIPV Testing and Evaluation Project has combined relevant sources of data, detailed analyses, reporting, Web access, presentations, and training as a way of providing the decision making information

4.1 Conclusions

Conclusions below are organized similar to the detailed sections of Project Outcomes

4.1.1 System Ratings

This research supports the results from other PV performance tests showing that many modules produce less than their nameplate rating when field-measured performance data are normalized to nameplate conditions. This typical shift of product toward the lower end of the power warranty range is further exacerbated when put in the perspective of the world PV market. As other markets around the world demand products with a tighter tolerance than California and the rest of the United States, it is nearly certain that the U.S. markets will continue to receive product at the low end of published power tolerances (See **Figure 31** for an illustration of this point). This underlines the need for enforced performance requirements, and a verification process to ensure that consumers and installers are receiving product that meets these requirements.

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9 An acknowledgement of the Project Team's strong belief that this project should continue in some fashion.

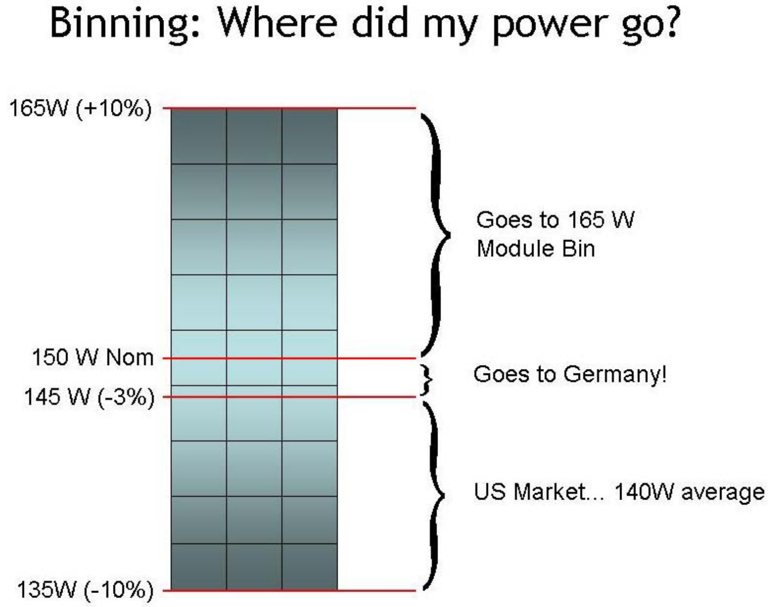

Figure 31 Illustrative example of a hypothetical 150-Watt rated (nominal) module with a claimed ±10% tolerance. Based on German 3% tolerance requirement and other anecdotal information.

While PV module rating shortfalls continues, the practice of assigning system ratings based solely on the output of PV modules under laboratory conditions will remain a source of system performance misinformation.

4.1.2 System Performance

The three small system segments under test at the PVUSA test facility provided an ideal arrangement for evaluating commercially available residential PV products in a side-by-side comparison. The annual yields from the three arrays averaged approximately 1,750 kWh/kW AC-rated (1,430 kWh/kWp). Compared to typical residential yields for systems installed under the Emerging Renewables Program, these researched systems are positioned at the high end of measured performance. Most recent California installations tend to generate at least 20% less (roughly 1,100 kWh/kWp [5]), primarily because of less-than-ideal mounting configurations—odd orientations and generally more shading.

Figure 32 shows that the yields based on PTC rating are consistently proportional to the normalized delivered energy (or yield in kWh/kWp) from each system. This correlation illustrates that the energy production of a variety of systems is very similar per rated PTC AC watt, but less similar per nameplate-rated STC watt. The STC ratings are a less predictable starting point for estimating energy production. STC ratings carry larger uncertainties than PTC because the field-based PTC ratings exclude manufacturing tolerances while STC does not. Furthermore, STC ratings do not come close to accounting for the typical operational temperature of the PV array.

To a first approximation the actual irradiation received in a year (in peak sun hours) represents a benchmark that PTC-based yields should approach.

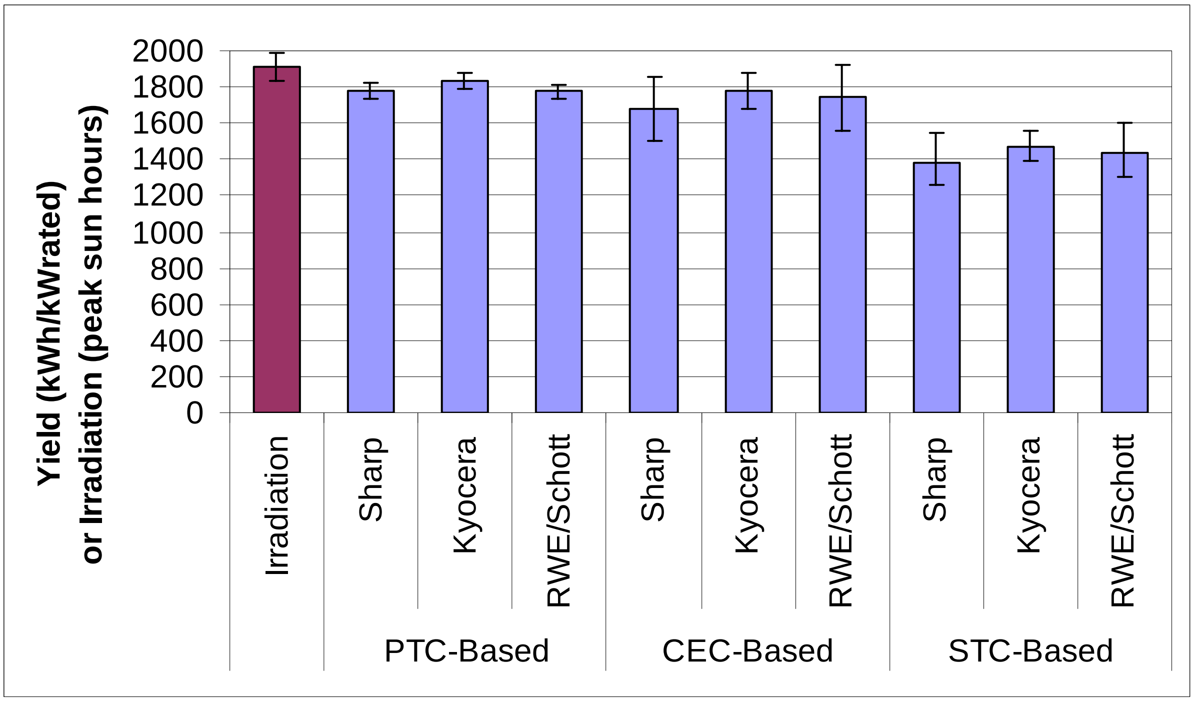

Figure 32 Summary of Yields Referenced to Different Ratings

The 12 large systems under test provide a unique opportunity to evaluate commercially available products side-by-side. Module efficiencies ranged from 5.6% to an industry-leading 16.1% with corresponding system-level efficiencies ranging from 3.4% to 7.9%. However, once the more accurate PTC_{AC} field AC rating was determined, the yield (energy production per rated PTC_{AC} Watt) of each system was very similar.

Predicted operating temperatures and voltages did not always match measured values, indicating challenges still exist in appropriately designing and rating systems. This is particularly important for new systems and new mounting configurations. This conclusion was evident in the fact that the AstroPower APx-130 array with the Solar Quilt structure operated at temperatures higher than expected, causing that system segment to operate below initial performance expectations.

Project field testing revealed intermittent problems with the Xantrex inverters that could otherwise have gone unidentified for some time, with the system owner not knowing why the system doesn't seem to produce as much energy as expected, only that it doesn't.

4.1.3 Reliability

There were no significant reliability issues identified during the short term of the project, which, of course, is one of the best project conclusions and a confirmation of solid industrywide quality. As a cautionary note, some reliability problems can take time to develop and be detectable. Only continued monitoring of the installed systems will determine if there are reliability concerns with these systems.

4.1.4 Technology Transfer

The project has gotten its message out:

- A total of 4,500 internet users have visited the project web site, downloading 400 copies of the available reports and presentations.
- Hundreds of scientists, engineers, manufacturers, installers, designers, and end users have had the opportunity to review project results in three conference presentations and related papers/proceedings.
- A total of 180 installers and other interested parties have attended three-day workshops.

The project incorporated new technology while taking significant advantage of readily available facilities and tools in implementing the Web page and real time display. The website has been a key resource for technology transfer among the project team members, with the TAC, with the rest of the Commonwealth Program, with equipment providers, and with other interested parties.

Training is key to the technology transfer for the PV industry installer base. Although Web-based information is helpful in reaching a broader audience, and in particular the PV consumer, there is no substitute for putting installers in a room and directly communicating key project results and lessons learned. The questions and discussion that transpire in a workshop environment cannot be reproduced through other communication channels. Although direct training cannot satisfy all the technology transfer goals of a project like this, it must be included in the overall scheme to communicate results effectively.

4.2 Commercialization Potential

In addition to the many other goals and objectives of this project, this work was intended specifically to address the Commerce Energy decision making process in an optimal mix of renewable energy. High level executives at Commerce Energy have continuously been apprised of this project, as well as the other renewable energy projects in the programmatic portfolio of PIER research being managed by Itron. Though the utility environment that prompted Commerce Energy to submit their original proposal (or direct access) no longer exists, and despite the limited results of the follow-on commercialization project (Project 3.3), Commerce still considers PV a viable option for serving some of its existing customers' energy needs.

The PV industry, California's various photovoltaic incentive programs, consumers, and other stakeholders are using, and will continue to use, this project's on-line side-by-side systems evaluation for further refinement of solar electric goals. In addition to many evaluations performed during this project, the ratio of PTC/STC obtained for the various systems provides a good initial indication of consumer value by comparing actual to claimed performance.

If the project were to continue, there is a Photovoltaic of some covering some portion of operational costs through fees to the participants, though the fee would have to be nominal and participation would have to be mandated, for example, as a prerequisite to getting on the approved equipment list. This approach might prove particularly beneficial for vendors with new technologies (for example, the Energy Commission has received inquiries from several concentrator and bifacial module suppliers) that don't have a clear path to getting on the approved equipment lists.

4.3 Recommendations

At the end of this project, in January 2006, the California Public Utilities Commission approved the California Solar Initiative: a 10-year, $2.9 billion program designed to help California move toward a cleaner energy future and help bring the costs of solar electricity down for California consumers. The Energy Commission will manage $350 million targeted for new residential building construction using funds already allocated to the Energy Commission to foster renewable projects between 2007 and 2011. The Energy Commission should be applauded for the foresight in funding this first systems level PV research project. It is recommended that a small percentage of state funding continue to assure that the major portion of ratepayer funds are appropriately applied to properly performing PV systems. This project is an investment into side by side evaluations that can continue to provide stakeholders realistic performance assessments, thus enabling economic evaluations.

As a result of our work on this project, four key recommendations can be enumerated:

1. Requirements for system and component ratings need to be established and verified through 3rd-party comparative testing.
2. System and component characteristics need to be evaluated to ensure that performance benefits are understood.
3. Assessment of reliability requires continued long-term monitoring of installed systems.
4. The information that can potentially continue to flow from the project needs to be transferred by different means to the different members of the PV community.

4.3.1 System Ratings

In 2005, the Energy Commission's Emerging Renewable Program imposed standardized performance testing and reporting requirements for PV inverters to address industry concerns about manufacturer's claims. Project results verify that there is a similar need for PV modules. We suggest that the Energy Commission adopt a requirement for PV modules specifying that the manufacturer's nameplate rating shall represent the minimum allowable output for that model. This rating should also include an allowance for initial light-induced degradation, which is commonly addressed in thin-film modules but which has some measurable impact on all PV technologies. The following change is suggested for the ERP Guidebook:

The PV module Nameplate (STC) Power Rating shall represent the minimum output power for that model based on qualified production line measurements and shall include an adjustment for initial light induced degradation. This rating shall also represent the value from which the warranty power tolerance is calculated.

Currently, modules sold into California are provided with a power rating tolerance of ±5% to ±10%, which is defined by the manufacturer. This means that a module with an STC Nameplate Rating of 150 watts could have an actual rating of between 135 W and 165 W, based on manufacturer factory testing. Due to market pressure and other circumstances, the actual rating of an individual module rarely meets, let alone exceeds, the nameplate rating, thus measured system performance continues to fall short of expectations. European procurements typically require a tighter tolerance (±3%) than is normally provided in the United States, and evidence suggests that California and other United States consumers get modules below this 3% tolerance.

The suggested change would simply require that the module rating represent the minimum of the tolerance, for example, 135 W in the above example. The manufacturer could provide whatever tolerance band it felt appropriate. If the Commission were to instead impose a tighter European-style tolerance, manufacturers would have to create additional models to accommodate the range of power levels they already produce, and there would still be a question about lot averages, and so forth.

Also, the change would require all technologies to include an adjustment for initial light-induced degradation. Such an adjustment has, for a decade or more, been standard practice with thin film modules that exhibit 5% to 20% reduction in output power over the first few weeks or months of operation. All PV technologies exhibit some amount of LID, though with crystalline silicon, for example, the degradation is small (1-3% of initial rated power) and occurs within the first few hours or days of exposure. This suggested change would create a level requirement for all technologies.

Impact: Proposed change will

1) Improve the actual versus expected performance of most PV systems sold into the ERP.
2) Likely change the ratings for some models.
3) Result in no additional testing or administrative requirements since manufacturers already test and bin each module coming off the factory line.
4) Possibly increase the price-per-watt for some products as much as 3% to 10%. If the price per module remains unchanged, which it should, the price per kWh would remain unchanged.

Note that this suggested change would be just as valuable in a performance based incentive (PBI) environment as it is in a rebate, since in either case, the key components—PV modules and inverter—are marketed, compared, and bought based on their rated output power (a trait of all generation equipment, renewable or conventional). The more accurately the designers know a device's output power, the more likely they are to be able to predict installed system rating or annual energy production.

4.3.2 System Performance

This project was proposed in 2001 to look at commercially available PV components and systems, to feed information back to the equipment providers, and forward to the PV-buying public, and to document how it was done. The systems tested represent the state of the industry in late 2003, an industry that has been anything but static. There are many new modules and inverters, several new mounting options, and system integrators old and new that have learned quite a few tricks. There is still no other place for these products to be sent for reliable third-party evaluation.

Another reality that must be acknowledged is that there are fewer packaged systems today then there were three years ago. This may present a significant challenge as the state moves back toward an emphasis on residential-style PV for retrofits and especially for new homes. Though the packaged system has long been postulated as a key to a reduced-cost PV system, the reality is that system providers have found a need to customize the design of most systems they install. Thus system designers still need accurate component information. The recommendation under the previous section would provide a lower limit on module performance and simplify the designer's job considerably. Our system performance recommendation includes further component testing to address the primary need of the system designer and integrator. System testing would be done based either on packaged systems, when they exist, or on some version of the designer's product (even customized systems have some common features). Systems would be selected based on the use of components not used in other tested systems or used in unique arrangements or on some unique feature.

Building on both the ongoing framework for the Energy Commission's listing of eligible products, as well as that of the systems evaluations in Chino and Davis, we anticipate a superior project would consist of the following:

- **An enhanced eligible module listing procedure**. A procedure in which the principal classes of existing and newly listed PV modules will undergo a short-term (2-3 week) evaluation on fixed-tilt structures next to the existing PIER test site in Davis. By field-rating modules to PVUSA test conditions using a random sample of 12-20 modules, the rebate program's eligible module list would achieve the improved accuracy and realistic ratings needed by an increasingly payback-sensitive block of consumers. While not all modules would be required to undergo the field procedure, each manufacturer's principal class of products would be tested, with small variant products scaled to assign the new Energy Commission rating. Various carrot or stick approaches to implementing this piece should be considered. An extended version of this test would also provide some new products not addressed by current UL standards (concentrator PV modules for example) an opportunity for an alternate path to the approved list or an alternate list of partially qualified products.
- **Extension to inverter performance characterization**. While new procedures have been implemented by nationally recognized test labs to determine and improve

representative inverter efficiency listings, several manufacturers have suggested that a single-facility test arrangement would better serve all parties by removing the burden on manufacturers of setting up and maintaining the necessary testing equipment and facilities and removing some lingering doubt about consistency of results among different testing laboratories, nearly all of whom currently witness testing done using the manufacturer's test equipment and facilities. Such testing could possibly be performed at PG&E's Modular Generation Test Facility, where the Energy Commission-funded DUIT project is operating.

- **System-level initial evaluation**. At this sample size, representative residential-scale systems can be installed. Gaps existing in our present knowledge of system-level loss factors such as mismatch, wire losses, light-induced degradation, and even dust losses may be ascertained. System-level data will be used to evaluate field-varying efficiencies and to gauge inverter maximum power-point tracking (MPPT) effectiveness. MPPT non-idealities have historically plagued several new inverter products.
- **Longer-term energy yield information**. Systems would remain in place at the PVUSA facility in Davis, California. Ongoing system-level monitoring and periodic key performance reporting will enable the state to accurately characterize kWh energy production per installed kW as a stepping-stone toward performance-based incentives that are increasingly guiding PV economic decision-making in key grid-tie markets. This long-term monitoring would also support the reliability question discussed in the following section.

4.3.3 Reliability

Before this project, side-by-side systems testing information was rarely available. Now, these systems' evaluations are available to all who have an interest in PV through the Energy Commission documents Web page (http://www.energy.ca.gov/reports/index.html), the Commerce Energy PIER program website (www.pierminigrid.org) and the BIPV Evaluation and Testing website (www.pierminigrid.showdata.org). Continued monitoring is needed to assess the performance and reliability of these PV systems over time. This information has ongoing value needed by the PV-buying public. With the newer, less proven technologies, it is especially important to provide the consumer with confidence that these products will continue to perform as expected.

We recommend that maintenance funding be provided for both the small and large PV systems evaluations developed during this project to provide this ongoing confidence.

Funding would be needed to cover website hosting, data handling, monitoring system maintenance, and providing periodic DAS maintenance.

4.3.4 Technology Transfer

Getting the message out will remain a vital project function. The monitoring maintenance funding recommended in Section 4.3.3 would cover only the continued operation of the existing monitoring and Web presence. Additional funding should be applied to enhance the Web presence for any new systems, to expand and automate additional analyses (see the *Large System Interim Report*, for example), and to report any new results through various documentation and presentation options.

Further, continued training is clearly important to the long-term success of the PV industry. As the body of knowledge about PV components, system design, and performance continues to grow, that information needs to be communicated to the companies implementing these systems. A more informed industry is better equipped to avoid the mistakes of the past and build on its successes. A strong future PV industry is founded on solid information and defensible evidence from past experience. Targeted training is a key aspect of that foundation.

4.4 Benefits to California

California represents, by far, the largest PV market in the U.S. (traditionally about 80%), so nearly every action advancing PV benefits California. The State of California is also the largest investor in installed PV systems in the country—far exceeding even the federal government in funding system installations. This project supports the investment California has made, and will continue to make, in reliable PV systems with associated expectations on system performance. In particular, the following project attributes have California-centric characteristics:

1. All of the products reviewed are in use in the California PV market.
2. Reviews were performed in key California climates.
3. The project provided an opportunity for Commerce Energy, a California electric service provider, to develop an on-site renewable energy power purchase arrangement.
4. The project provided an opportunity for several key California system integrators to display their products.

5. The project directly influenced the development of the Sandia Inverter Test Protocol and the ERP-specific requirements for performance testing that all inverters must now go through.
6. In addition to many evaluations performed during this project, the ratio of PTC/STC and PTC/the Energy Commission obtained for the various systems provides a good initial indication of consumer value by comparing actual to claimed performance. (PTC/the Energy Commission comparisons in particular provide the California consumer a confidence benchmark.)
7. This project helps all California purchasers of PV by enabling side-by-side evaluations. Dependent upon investment size, the informed purchasing decision maker will consult this project before proceeding.
8. The modular nature of PV technology enables smaller 20 kW systems to be representative of larger megawatt installations.
9. This project, and California, benefited by cost sharing of all the PV systems evaluated.

5. Glossary

The following definitions and acronyms are used in this report:

AC	Alternating current. A type of electrical current that changes direction at regular intervals. In the US, the standard frequency is 60 cycles per second.
Amorphous Silicon	The element "silicon" solidified with no apparent crystalline structure. Used as a base product for developing certain thin-film photovoltaic cells.
a-Si; 3a-Si	Amorphous Silicon; Triple-Junction Amorphous Silicon.
ASTM	American Society for Testing and Materials (officially, ASTM International, www.astm.org)
BIPV	Building Integrated Photovoltaics
CdTe	Cadmium Sulfide/Cadmium Telluride.
The Energy Commisison	California Energy Commission (officially, the State Energy Resources Conservation and Development Commission). (www.energy.ca.gov, www.consumerenergycenter.org/renewable/index.html)
CIS	Copper Indium Diselenide.
Commerce Energy	Program Prime Contractor (www.commerceenergygroup.com)
CSI	California Solar Initiative.
DAS	Data Acquisition System. Also see SCADA. A system that receives (and sometimes sends control) data from one or more locations. From IEEE Std. 100-1996.
DC	Direct current. A type of electrical current that flows in one direction. Batteries and PV modules supply DC current.
Disconnect Switch	A switching device that breaks an electrical circuit. These devices may have ac or dc voltage and current ratings and may or may not be rated for breaking under load. Disconnect switches usually provide a visible break, and may have a locking feature to provide control over the status of the disconnect switch.
Efficiency	The ratio of the output power or energy to the input power or energy.
ERP	Emerging Renewables Program, of the California Energy Commission program whose goal is to develop a self-sustaining market for "emerging" renewable energy technologies in distributed generation applications. (www.energy.ca.gov/renewables/emerging_renewables.html)
FSEC	Florida Solar Energy Center (www.fsec.ucf.edu)

Grid	An integrated utility system of electricity generation and distribution consisting of the wires, transformers, substations, power plants and control systems.
HIT	Heterojunction with Intrinsic Thin layer. A mono-crystalline silicon photovoltaic material surrounded by thin amorphous silicon layer. A photovoltaic material used for making PV modules.
IEC	International Electrotechnical Commission (www.iec.ch)
IEEE	Institute of Electrical and Electronics Engineers (www.ieee.org)
IEUA	Inland Empire Utilities Agency (www.ieua.org)
Interconnection	The physical plant and equipment required to help the transfer of electric energy between two or more entities. It can consist of a substation and an associated transmission line and communications facilities or only a simple electric power feeder.
Inverter	A machine, device, or system that changes direct-current power to alternating-current power. Common usage of the term implies all of the input and output power processing, control, and user interface included in the term PCU. See also PCS, PCU, and static power converter .
IOU	Investor-owned utility, owned by shareholders.
Islanding	A condition in which a portion of the utility electric system that contains both load and operating generation is isolated from the remainder of the utility system. Of particular interest here is the Dispersed Generation Island, a condition in which the generating source(s) supplying the loads within the island are not within the direct control of the power system operator.
I-V Curve	A plot of the PV array or module current versus voltage characteristic curve.
kW	Kilowatt. A standard unit of electrical power equal to 1,000 watts, energy flow at a rate of 1,000 joules per second. Subscript ptc: PVUSA Test Condition, used when describing the AC output of an actual PV system at these conditions. Subscript DC: Direct Current. Subscript AC: Alternating Current. Subscript stc: Standard Test Condition, used when describing the power rating of PV modules and arrays.
kWh	Kilowatt-hour. 1,000 thousand Watts acting over a period of 1 hour, 500 Watts over 2 hours, etc.. The kWh is a unit of energy. 1 kWh=3,600 kilo Joules.
kWp	"Peak" kilowatts, used to denote PV DC power output when the module or array voltage is at the best value for power production under STC conditions.

LID	Light-induced degradation. A mechanism of degradation of the photovoltaic effect driven by exposure to light. This mechanism typically reaches its maximum effect within hours to weeks of initial exposure to sunlight. The maximum effect is very pronounced in a-Si PV materials, and very weak in m-Si materials.
Listed Equipment	Equipment, components or materials included in a list published by an organization acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials, and whose listing states either that the equipment or materials meets appropriate standards or has been tested and found suitable for use in a specified manner. (from the National Electrical Code; Article 100.)
mc-Si	Mono-crystalline silicon.
Megohmmeter	A direct-reading instrument for measuring electric resistance that applies several hundred volts to the test leads, typically to confirm that electrical insulation is intact. It is provided with a scale, usually graduated in ohms, megaohms, or both.
Mono-Crystalline Silicon	The element "silicon" solidified as a single macroscopic crystal. Used as a base product (most commonly in thin slices) for developing photovoltaic cells.
MPP	Maximum Power Point. The point on the array I-V Curve that yields the greatest output power.
MPPT	Maximum Power Point Tracker, or Tracking. A function included in an inverter or in a separate device that attempts to operate and maintain a PV array at its MPP.
MW	Megawatt. 1,000 kilowatts, or 1 million watts.
MWh	Megawatt-hour.
NCPV	National Center for Photovoltaics (www.nrel.gov/ncpv)
NEC	National Electrical Code (NFPA 70; www.nfpa.org)
NREL	National Renewable Energy Laboratory the primary federal laboratory for renewables, located in Golden, Colorado (www.nrel.gov)
NYSERDA	New York State Energy Research and Development Authority (www.nyserda.org, www.powernaturally.org)
Parallel/ Paralleling	Strictly, it is the act of synchronizing two independent power generators (or the utility and a PV power plant) and connecting or "paralleling" them onto the same electrical connection. In practice, it is used interchangeably with the term interconnection. IEEE 100 Def: The process by which a generator is adjusted (synchronized) and connected to run in parallel with another generator or system.

PBI	Performance-based incentives. Incentives that include some component of payment for actual energy produced rather than paying solely by the power rating of the system.
pc-Film	Poly-crystalline silicon film.
PCS	Power conditioning subsystem. (terrestrial photovoltaic power systems). The subsystem that converts the DC power from the array subsystem to DC or AC power that is compatible with system requirements. See inverter.
pc-Si	Poly-Crystalline Silicon.
PCU	Power Conditioning Unit. A device that converts the DC output of a PV array into utility-compatible AC power. The PCU may include (if so equipped) the array maximum power tracker, protection equipment, transformer, and switchgear. See also "inverter".
PIER	Public Interest Energy Research.
Poly-Crystalline Silicon	The element "silicon" solidified with multiple crystal orientations. Used as a base product (typically in slices) for developing photovoltaic cells.
Poly-Crystalline Silicon Film	The element "silicon" solidified with multiple crystal orientations by deposition onto a ceramic substrate. Used as a base product for developing photovoltaic cells.
PowerMark	PowerMark Corporation provides PV manufacturers with a module certification program that verifies the quality of their modules. www.powermark.org
PTC	PVUSA Test Conditions, (sometimes Performance Test Conditions or Project Test Conditions). A fixed set of ambient conditions specified as a dry-bulb temperature of 20 ºC, an in–plane irradiance of 1,000 W-m^{-2} global for flat-plate modules or 850 W-m^{-2} for concentrators, and a wind speed of 1 m-s^{-1}, at which electrical performance of the PV system is rated. This set of conditions was originally defined for use in utility scale PV power system procurements by the PVUSA PV test project (See PVUSA).
PV	Photovoltaic. Capable of producing a voltage when exposed to radiant energy, especially light.
PV Array	An interconnected system of PV modules that function as a single electricity-producing unit. The modules are assembled as a discrete structure, with common support or mounting. In smaller systems, an array can consist of a single module.
PV Module	The smallest environmentally protected assembly of solar cells.
PV System	A complete set of components for converting sunlight into electricity by the photovoltaic process, including the array and balance of system (BOS) components.

PVUSA	Photovoltaics for Utility Scale Applications. A utility-scale PV test project that ran from 1987 to 2000. Systems were acquired through a commercial utility procurement process, installed at a utility-controlled test facility, and evaluated for nearly a dozen years. The PVUSA Davis test site is now operated primarily as a power plant by Renewable Ventures, LLC.
R&D	Research and Development.
RPAC	Renewables Program Advisory Committee. A group of experts formed to review the progress of the PIER Minigrid Research Program, of which the BIPV Testing and Evaluation project is a part.
Sandia	Sandia National Laboratories Photovoltaics Systems Program (**www.sandia.gov/pv/**)
SCADA	Supervisory Control and Data Acquisition. A system operating with coded signals over communication channels so as to provide control of remote equipment (using typically one communication channel per remote station). The supervisory system may be combined with a data acquisition system, by adding the use of coded signals over communication channels to acquire information about the status of the remote equipment for display or for recording functions.
SGIP	The California Public Utility Commission Self-Generation Incentive Program. (**www.cpuc.ca.gov/static/Energy/Electric/051005_sgip.htm**)
SMUD	Sacramento Municipal Utility District, the municipal electric utility in Sacramento, California that provides electric power to Sacramento County (and a small part of Placer County).
SRC	Standard reporting conditions. For photovoltaic performance measurements, a fixed set of conditions that constitute the device temperature, the total irradiance, and the reference spectral irradiance distribution to which electrical performance data are translated. (See ASTM Std E 1328)
sr-pc	String ribbon poly-crystalline Silicon. A photovoltaic material used for making PV modules, formed by cooling a film of liquid silicon suspended between two fibers.
Static Power Converter	Any static power converter with control, protection, and filtering functions used to interface an electric energy source with an electric utility system. Sometimes referred to as power conditioning subsystems, power conversion systems, solid-state converters, inverter, or power conditioning units. See inverter.
STC	Standard Test Conditions. A particular set of **SRC** defined as 1,000 W-m^{-2} irradiance, 25 ºC cell temperature, and Air Mass 1.5 spectrum (See ASTM Std G173).

SWTDI	Southwest Technology Development Institute (**www.nmsu.edu/~tdi/**)
TAC	Project Technical Advisory Committee
UL	Underwriters Laboratory, an electrical safety testing certification organization. **www.ul.com**
UPVG	Utility PhotoVoltaic Group, the former name of SEPA, Solar Electric Power Association, a collaboration of utilities, energy service providers and the photovoltaic industry.
Utilization (Array Utilization)	The ratio of the energy (or power) that is actually extracted from the module or array to the maximum energy (power) potentially available from the array. Array utilization less than 1.0 is a result of inaccurate Maximum Power Point Tracking (see MPPT).

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